Proceedings of ISCM2006

International Workshop on Institutional View of SCM
November 16-18, 2006, Tokyo, Japan

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De-bi Cao (Keio University)
Sadami Suzuki (Tokyo Institute of Technology)

Sponsored and organized by SIMOT (Science for Institutional MOT)
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PREFACE

The idea to organize this workshop is originally proposed by the research group of reverse logistics of the JIMA (Japan Industrial Management Association) URL:www.revlog.jp Through numerous research discussions during last two years, we found that the harmony and virtuous cycle between the practice and theory, between the national issue and the organizational issue are very important to the sustainable development and it provides basic competition power to society and organizations. Focusing on the supply chain management (SCM), the optimal solution to problems in supply chain management may change under different constraints, whether those constraints are internal to the supply chain or are part of the institutional context in which the supply chain exists. Accordingly, best practice for a given organization may not generate best performance in a different organization or a different country. A better understanding of the institutional considerations in SCM would not only contribute to improved performance of individual supply chains but would also contribute to the sustainable development of national and global economies. Institutional issues in SCM may be considered in terms of three perspectives or axes: (1) national and global-level issues and infrastructures, (2) organizational-level issues and constraints, (3) historical co-evolution of supply chain management practices and their institutional context.

After distribution of the CFP, we received many creative ideas and contributions and finally accepted 41 abstracts, and we were able to include 32 full papers and 4 abstracts in this proceeding. These papers were classified into 5 categories, i.e., (1) Supply Chain Optimization, (2) SCM Performance and IT, (3) Closed loop Supply Chain / Reverse Logistics, (4) Global SCM, (5) SCM Strategy, and presented in 6 parallel sessions during November. 17-18, 2006.

Finally, I would like to express my sincere thanks to all authors for contributing high quality papers to the workshop, and special thanks to professor Robert W. Grubbstrom and professor Stephen C. Graves, for their kind encouraging and support.

Wish you enjoy and have a good time in the workshop ISCM2006 in Tokyo, Japan.

Dr. De-bi Cao
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ON PRODUCTION PLANNING IN CLOSED-LOOP SUPPLY CHAIN SYSTEM UNDER CONSIDERATION OF IMPACT OF GREEN IMAGE FACTOR ON REMANUFACTURING ACTIVITY

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ABSTRACT

In this paper, we discuss a production planning in the closed-loop supply chain system which consists of a manufacturing facility to produce a final product, a remanufacturing facility to produce a recycled component and a new production facility to produce a new component. Under the situation where the recycle cost of the component is more expensive than the new production cost of it, by considering the balance of reduction of the recycle cost as to the production quantity of the recycled component and increase of the customer demand expected as the green image factor from the remanufacturing activity of the enterprise, the optimal production policy in the closed-loop supply chain system is investigated. So as to maximize the profit in the closed-loop supply chain system, the optimal production ratios of the component at the remanufacturing facility and the new production facility are determined based on the periodic ordering system in inventory management. In numerical examples, impacts of both the green image factor by the remanufacturing activity and reduction of the recycle cost as to the recycle ratio on the production policy in the closed-loop supply chain system are demonstrated as the motivation to encourage the remanufacturing activity in the system.

INTRODUCTION

Because of the finiteness of natural resources and the growth of concerns to environment problems, the reuse of final products or components has become the significant resources for the replenishment of materials in various enterprises. In recent years, it has been necessary to develop a closed-loop supply chain system with the joint production facility(or process) which consists of the new production and the remanufacturing and evaluate the economical effect for the system (See van der Lann and Salomon 1997, Kistner and Dobos 2000, Fleischmann 2001, Dobos 2002, Kiesmuller and Minner 2003 and Kiesmuller 2003). As the factor to encourage the remanufacturing activity in the system, in most investigations of the production policy of the joint production facility(or process) with the new production and the remanufacturing, it has been assumed that the recycle cost of either the product recycled from the used product or the component recycled from the reusable material after disassembly of the used product is less expensive than the new production cost of either the new product produced from the new component or the new component produced from the new material. However, in the real world, it is known that the recycle cost is often more expensive than the new production cost. This fact might cause a negative trend for the remanufacturing activity in the enterprise. On the other hand, the green image of the enterprise by the remanufacturing activity might frequently enhance the corporate earnings (See Georgiadis and Vlachos (2004)). Further, increase of the recycled quantity might reduce the recycle cost. These effects might encourage the active remanufacturing activity to the enterprise.

In this paper, we discuss a production planning in the closed-loop supply chain system which consists of a manufacturing facility to produce a final product, a remanufacturing facility to produce a recycled component and a new production facility to produce a new component. Under the situation where the recycle cost of the component is more expensive than the new production cost of it, by considering the balance of reduction of the recycle cost as to the production quantity of the recycled component and increase of the customer demand expected as the green image factor from the remanufacturing activity of the enterprise, the optimal production policy in the closed-loop supply chain system is investigated. So as to maximize the profit in the closed-loop supply chain system, the optimal production ratios of the component at the remanufacturing facility and the new production facility are determined based on the periodic ordering system in inventory management. In numerical examples, impacts of both the green image factor by the remanufacturing activity and reduction of the recycle cost as to the recycle ratio on the production policy in the closed-loop supply chain system are demonstrated as the motivation to encourage the remanufacturing activity in the system.

NOTATION

P_a : the production ratio of the recycled component at the remanufacturing facility($0 \le P_a \le 1$), called the recycle ratio

P_b : the production ratio of the new component at the new production facility ($P_b = 1 - P_a$) , called the new production ratio

$I_p(t)$: the on-hand inventory of the final product in the manufacturing facility of the final product at the beginning of period t

$I_a(t)$: the on-hand inventory of the recycled component in the remanufacturing facility at the beginning of period t

$I_b(t)$: the on-hand inventory of the new component in the new production facility at the beginning of period t

$Q_p(t)$: the total ordering quantity of the component from the manufacturing facility of the final product to both the remanufacturing facility to produce the recycled component and the new production facility to produce the new component at the beginning of period t

$Q_a(t)$: the recycling quantity of the reusable material in remanufacturing facility determined at the beginning of period t

$Q_b(t)$: the procurement quantity of the new material in the new production facility determined at the beginning of period t

$D(t)$: the customer demand of the final product in period t

L_t : the delivery time of the component or the material (a fixed value)

L_p : the production time required to produce the required quantity of the final product at the manufacturing facility of the final product, called the manufacturing lead time

L_a : the production time required to produce the required quantity of the recycled component at the remanufacturing facility, called the remanufacturing lead time

L_b : the production time required to produce the required quantity of the new component at the new production facility, called the new production lead time

H : the ordering cycle to each facility to produce the final product, the recycled component and the new component ($\leq L_X$ ($X = p$, a or b))

t_p : the production time per unit of the final product

t_a : the production time per unit of the recycled component

t_b : the production time per unit of the new component

C_s : the sales price per unit of the final product

C_p : the manufacturing cost per unit of the final product including the delivery cost per unit of the component

$C_a(x)$: the recycle cost per unit of the recycled component including the costs on collection, disassembly inspection of the reusable material to produced a unit of the recycled component when the remanufacturing ratio is x, called the recycle cost

C_b : the new production cost per unit of the new component including the procurement cost of the new material required to produced a unit of the new component, called to the new production cost

h_p : the inventory holding cost per unit of the final product per unit of time

h_u : the inventory holding cost per unit of the recycled component or the new component per unit of time ($h_u < h_p$)

T : the production planning period

m : the increasing ratio of the customer demand of the final product expected as the green image factor from remanufacturing activity

$G(t)$: the profit function of the closed–loop supply chain system in period t

MODEL ASSUMPTIONS

(1) In this paper, A closed-supply chain system is addressed as shown Figure 1. A single final product, a single component and a single material are considered. The single final product is produced from either the single new component only or the single recycled component only and both components. Concretely, the single new component is produced from the single new material at the new production facility. The single recycled component is produced from the single reusable material at the remanufacturing facility. The single new material is procured from a supplier. The single reusable material is available after the used products collected from the customer are collected, disassembled and inspected. It is assumed that the recycled component can be produced from the reusable material so as to have the same quality of the new component produced from the new material. It is assumed that the final product can be produced from either the only new component or the only recycled component which have as the same quality as the new component or both components.

(2) When the remanufacturing activity is not practiced (the recycle ratio $P_a = 0$), the customer demand follows the normal distribution with mean μ_D and variance σ_D^2. When the remanufacturing activity is practiced (the recycle ratio $P_a > 0$), it is expected that mean of the customer demand is increased to $\mu_D(P_a)$ as to the recycle ratio of the component P_a at the remanufacturing facility. In this paper, as the effect of the green image expected by the remanufacturing activity, by using the increasing ratio of the customer demand of the final product m and the recycle ratio P_a, increase of mean of the customer demand is considered as

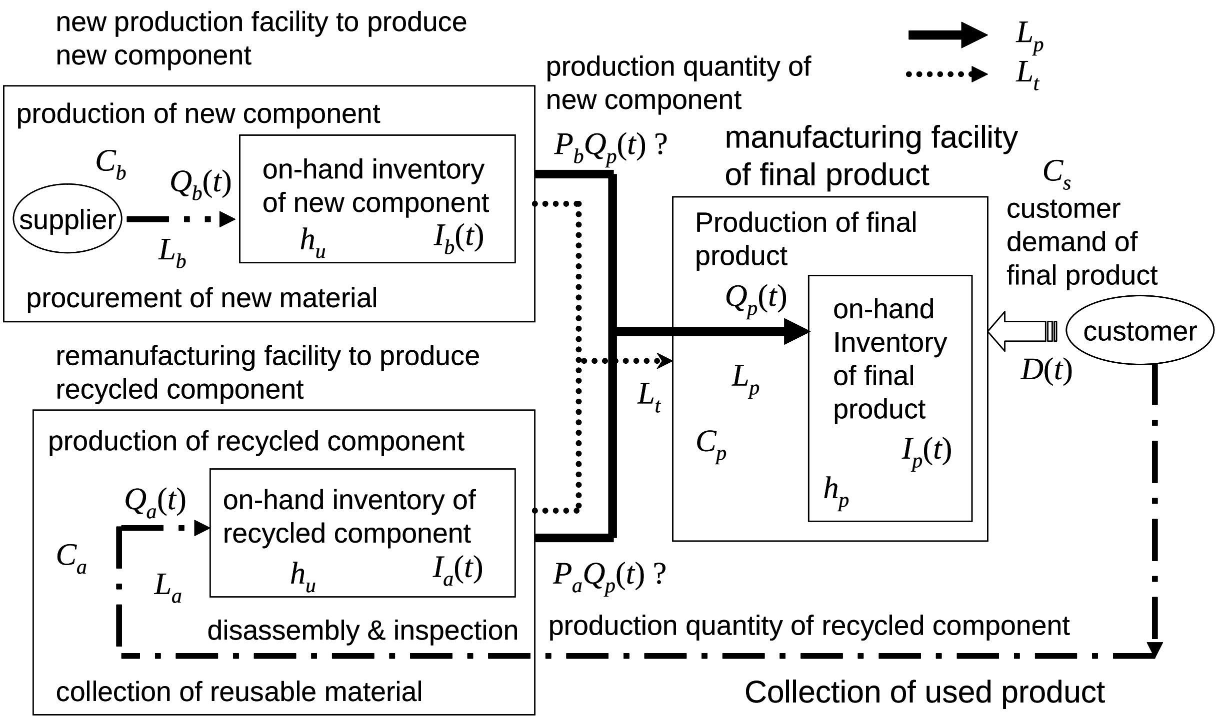


Figure 1 A closed-loop supply chain system

$$\mu_D(P_a) = \mu_D \times (1 + mP_a) \qquad (if\ P_a > 0)\ , \tag{1}$$

$$\mu_D(P_a) = \mu_D \qquad (if\ P_a = 0)\ . \tag{2}$$

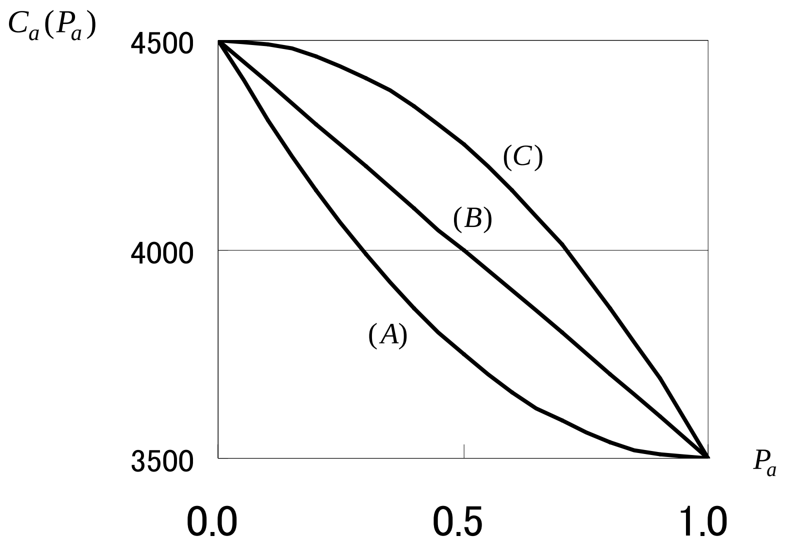
(3) At the beginning of each period, any orderings are placed to each facility. This means that the ordering cycle H to each facility to produce the final product, the recycled component or the new component is 1.

(4) It is assumed that the recycle cost can be reduced to $C_a(P_a)$ as to the value of the recycle ratio P_a of the component at remanufacturing facility. The purpose of this paper is to investigate the effect of the remanufacturing activity on the production policy in the closed-loop supply chain system. Therefore, the new production cost C_b is constant regardless of the value of the new production ratio P_b. As shown in Figure 2, in this paper the following decreasing functions are used to demonstrate the reduction pattern of the recycle cost as to P_a :

(A) $$C_a(P_a) = (C_b - C_a(0))P_a + C_a(0)\ , \tag{3}$$

(B) $$C_a(P_a) = (C_a(0) - C_b)(P_a - 1)^2 + C_b\ , \tag{4}$$

(C) $$C_a(P_a) = (C_b - C_a(0))P_a{}^2 + C_a(0)\ . \tag{5}$$



(A) $C_a(P_a) = (C_b - C_a(0))P_a + C_a(0)$

(B) $C_a(P_a) = (C_a(0) - C_b)(P_a - 1)^2 + C_b$

(C) $C_a(P_a) = (C_b - C_a(0))P_a{}^2 + C_a(0)$

Figure 2 Decreasing functions to demonstrate reduction pattern of recycle cost for P_a

(5) The Manufacturing lead time L_p until the required quantity of the final product is held as the on-hand inventory and is available at the manufacturing facility of the final product can be estimated as summation of the delivery time of the component L_t from either the remanufacturing facility or the new production facility to the manufacturing facility of the final product and the expected production time $t_p(\mu_D(P_a))$ required to produce the required quantity of the final product with consideration of increase of mean of the customer demand expected by the effect of the green image from the remanufacturing activity.

(I) the manufacturing lead time L_p required to produce the required quantity of the final product

$$L_p = L_t + t_p\left\{\mu_D(P_a)\right\}. \tag{6}$$

The remanufacturing lead time L_a until the required quantity of the recycled component is held as the on-hand inventory and is available at the remanufacturing facility of the component can be estimated as the expected remanufacturing time $t_a(\mu_D(P_a))$ required to produce the required quantity of the recycled component with consideration of increase of mean of the customer demand expected by the effect of the green image from the remanufacturing activity. In the same way as L_a , the new production lead time L_b can be estimated. Therefore, $L_Y\left(Y = a \text{ or } b\right)$ can be obtained as follows:

(II) the remanufacturing lead time or the new production lead time $L_Y\left(Y = a \text{ or } b\right)$ required to produce the required quantity of the recycled component or the new component

$$L_Y = t_Y\left(P_Y\left\{\mu_D(P_a)\right\}\right). \tag{7}$$

(6) Even if the on-hand inventory of the final product of the manufacturing facility of the final product does not satisfy the customer demand, the shortage penalty cost depending on the unsatisfied quantity for the customer demand is not incurred to the system profit here. The unsatisfied quantity for the customer demand is not counted as the backorder in the next period.

PRODUCTION POLICY IN CLOSED-LOOP SUPPLY CHAIN SYSTEM

In this section, the production policy in the closed-loop supply chain system addressed in this paper is discussed based on the periodic ordering system in the inventory management. Concretely, first, the total ordering quantity $Q_p(t)$ of the component to either the remanufacturing facility only, the new production facility only or both facilities from the manufacturing facility of the final product at the beginning of period t is determined based on the periodic ordering system in the inventory management. The total ordering quantity $Q_p(t)$ of the component from the manufacturing facility of the final product at the beginning of period t is determined by comparing present time t with the manufacturing lead time L_p.

(I) The total ordering quantity $Q_p(t)$ of the component to either the remanufacturing facility only, the new production facility only or both facilities from the manufacturing facility of the final product at the beginning of period t

(1) in the case that $1 \leq t \leq L_p$

$$Q_p(t) = \mu_D\left(P_a\right)\left(H + L_p\right) + k\left(\alpha\right)\sigma_D\sqrt{\left(H + L_p\right)} - \sum_{i=1}^{t-1} Q_p(i) - I_p(t)\,. \tag{8}$$

(2) in the case that $L_p < t \leq T$

$$Q_p(t) = \mu_D\left(P_a\right)\left(H + L_p\right) + k\left(\alpha\right)\sigma_D\sqrt{\left(H + L_p\right)} - \sum_{i=t-L_p+1}^{t-1} Q_p(i) - I_p(t)\,. \tag{9}$$

Second, according to the recycle ratio P_a and the new production ratio P_b for the total ordering quantity $Q_p(t)$ of the component determined at the manufacturing facility of the final product at the beginning of period t, the required quantity of the recycled component $P_aQ_p(t)$ is allocated and ordered to the remanufacturing facility, and the required quantity of the new component $P_bQ_p(t)$ is allocated and ordered to the new production facility. Based on the periodic ordering system, according to the ordering quantity to the remanufacturing facility $P_aQ_p(t)$ and the ordering quantity to the new manufacturing facility $P_bQ_p(t)$, the required quantity of the reusable material $Q_a(t)$ to produce the required quantity of the recycled component and the required quantity of the new material $Q_b(t)$ to produce the required quantity of the new component are determined. The ordering quantity $Q_Y(t)(Y = a \text{ or } b)$ of either the reusable material from the remanufacturing facility at the beginning of period t or the new material from the new production facility at the beginning of period t are determined by comparing present time t with the remanufacturing lead time L_a or the new production lead time L_b.

(II) The ordering quantity $Q_Y(t)(Y = a \text{ or } b)$ of either the reusable material from the remanufacturing facility at the beginning of period t or the new material from the new production facility at the beginning of period t

(1) in the case that $1 \leq t \leq L_Y$

$$Q_Y(t) = P_Y\left(\mu_D\left(P_a\right)\left(H + L_Y\right) + k\left(\alpha\right)\sigma_D\sqrt{\left(H + L_Y\right)}\right) - \sum_{i=1}^{t-1} Q_Y(i) - I_Y(t)\,0. \tag{10}$$

(2) in the case that $L_Y < t \leq T$

$$Q_Y(t) = P_Y\left(\mu_D\left(P_a\right)\left(H+L_Y\right)+k\left(\alpha\right)\sigma_D\sqrt{\left(H+L_Y\right)}\right)-\sum_{i=t-L_Y+1}^{t-1}Q_Y(i)-I_Y(t)\,. \tag{11}$$

Here, each ordering quantity $Q_X(t)$ ($X = p$, a, or b) at each facility determined from equations (10)-(11) is obtained as the integer number by rounding up the decimal number.

In the period t, the profit $G(t)$ in the closed-loop supply chain system, called the system profit, is obtained from the sales of the final product in period t, the manufacturing cost of the final product at the manufacturing facility of the final product, the recycle cost of the recycled component at the remanufacturing facility of the component, the new production cost of the new component at the new production facility of the component, the inventory holding cost of the final product at the manufacturing facility of the final product, the inventory holding cost of the recycled component at the remanufacturing facility and the inventory holding cost of the new component at the new production facility. Therefore, the system profits in the period t $G(t)$ is formulated as

$$\begin{aligned}G(t) = {} & C_s\min\left\{I_p(t),D(t)\right\}-\left(C_p\left(\min\left\{I_a(t),P_aQ_p(t)\right\}+\min\left\{I_b(t),P_bQ_p(t)\right\}\right)\right)\\ & -C_a(P_a)Q_a(t)-C_bQ_b(t)\\ & -h_p\left[I_p(t)-D(t)\right]^+-h_u\left[I_a(t)-P_aQ_a(t)\right]^+-h_u\left[I_b(t)-P_bQ_b(t)\right]^+,\end{aligned} \tag{12}$$

where $[x]^+$ indicates $\max\{0, x\}$. Objective of this paper is to determine the optimal production ratio of the recycled component P_a^* at the remanufacturing facility to maximize the expected system profit in the closed-loop supply chain system for the production planning period T by using equation (12). If P_a^* is determined, the optimal new production ratio of the new component P_b^* at the new production facility can be obtained as $P_b^* = 1 - P_a^*$.

NUMERICAL EXAMPLES

In this section, the performance of the production policy proposed for the closed-loop supply chain system addressed in this paper is assessed through computer simulations. By the repeat trial for the production planning period T, the average value of the system profit, the average value of the inventory holding cost of the component and the average value of the stockout frequency are calculated for various values of the recycle ratio P_a and the new production ratio $P_b(= 1 - P_a)$ in the range from 0.0 to 1.0. The optimal values of the recycle ratio P_a^* and the new production ratio $P_b^*(= 1 - P_a^*)$ are determined by finding the maximal average value of the system profit. The details to implement the numerical experiment here are described as follows:

From equation (1), when the remanufacturing activity is not practiced and the only new production activity is performed, that is, the recycle ratio $P_a = 0$ and the new production ratio $P_b = 1$, the customer demand follows the normal distribution with mean μ_D and variance σ_D $N\left(\mu_D, \sigma_D^2\right) = N\left(1000, 200^2\right)$. From equation (2), when the remanufacturing activity is practiced, that is, recycle ratio $P_a > 0$, it is expected that as the effect of the green image, mean of the customer demand is increased to $\mu_D(P_a)$ as to the values of the recycle ratio P_a and the increasing ratio of the customer demand m. The rest of the system parameters for the numerical examples are given as $T = 300$, $H = 1, C_s = 100000$, $C_p = 2000$, $C_b = 3500$, $L_t = 1, h_p = 2000$, $h_u = 1000$. The recycle cost is obtained as $C_a(P_a)$ from the value of P_a and equations (3)-(5). Note that $C_a(0) = 4500$ when $P_a = 0$. $t_X\left(X = p, a \text{ or } b\right)$ is set in the range from 1/100 to 1/2000. m is set in the range from 0.0 to 0.8. Based on the values of P_a, $\mu_D(P_a)$, $L_X\left(X = p, a \text{ or } b\right)$ is obtained from equations (6) and (7).

During the period required until the ordering quantities of the final product, the recycled component and the new component are held as the on-hand inventory and are available at the manufacturing facility of final product, the remanufacturing facility of component and the new production facility of component, it is necessary to hold down the stockout of each facility. So, based on mean and standard deviation of the customer demand, $\mu_D(P_a)$ and σ_D, the manufacturing lead time L_p and the new production lead time L_b, at the beginning of period 1 only, the initial inventories including the safety stocks in the manufacturing facility of the final product and the new production facility of the new component are set to the following quantities:

(I) the initial inventory of the final product held in the manufacturing facility at the beginning of period 1 only

$$I_p(1) = \mu_D(P_a)L_p + k(\alpha)\sigma_D\sqrt{L_p}\,. \tag{13)]}$$

(II) the initial inventory of the new component in the new production facility held at the beginning of period 1 only

$$I_b(1) = P_b\left(\mu_D(P_a)L_b + k(\alpha)\sigma_D\sqrt{L_b}\right). \tag{14}$$

Note that the initial inventory of the recycle component in the remanufacturing facility is not considered, that is, $I_a(1) = 0$. During the period from the beginning of period 1 where the first ordering quantity is placed from each facility to the beginning of period $L_X{+}1(X = p \text{ or } a \text{ or } b)$ where the first ordering quantity from each facility is held as the on-hand inventory and is available at each facility, the quantity of initial inventory at each facility is not counted as the on-hand inventory at each facility. The safety coefficient $k(\alpha)$ of the safety stock in equations (7)-(10), (12), (13) is set to 1.65 to aim at the stockout level as $\alpha = 5\%$ statistically.

The computer simulation from period 1 to the production planning period T is counted as one trial. By varying the recycle ratio P_a and the new production ratio $P_b(=1-P_a)$ in the range from 0.0 to 1.0, after 100 trials for each system parameter mentioned above, the average value of the system profit, the average value of the inventory holding cost of the component and the average value of the stockout frequency are calculated. The optimal values of the recycle ratio P_a^* and the new production ratio $P_b^*(=1-P_a^*)$ are finally determined by finding the maximal average value of the system profit calculated from the computer simulations of the 100 trials for the production planning period T mentioned above. The results of numerical examples are summarized as follows:

[1] the effect of increase of the customer demand expected as the green image factor from the remanufacturing activity on the production policy in the closed-loop supply chain system

Table 1 shows that results of the optimal production policy obtained from the following numerical example 1: $t_p=1/2000$, $t_a=1/1000$, $t_b=1/100$.

Table 2 shows that results of the optimal production policy obtained from the following numerical example 2 : $t_p=1/2000$, $t_a=1/1000$, $t_b=1/500$.

Table 3 shows that results of the optimal production policy obtained from the following numerical example 3 : $t_p=1/2000$, $t_a=1/100$, $t_b=1/1000$.

Table 4 shows that results of the optimal production policy obtained from the following numerical example 4 : $t_p=1/2000$, $t_a=1/500$, $t_b=1/1000$.

Tables 1-4 show that the optimal production ratios, the optimal recycle ratio P_a^* and the optimal new production ratio $P_b^*(=1-P_a^*)$, the maximal average value of the system profit, the average value of the inventory holding cost of the component for the increasing ratio of the customer demand m $(0 \le m \le 0.8)$, the various values of the production time per unit of the final product t_p, the production time per unit of the recycled component t_a and the production time per unit of the new component t_b. Note that in Tables 1-4, the recycle cost is used as a constant value regardless of the value of the recycle ratio, that is, $C_a(P_a)=C_a(0)=4500$.

From Table 1, when the production time per unit of the recycled component t_a is substantially smaller than the production time per unit of the new component t_b, the optimal production ratios, the optimal recycle ratio P_a^* and the optimal new production cost $P_b^*(=1-P_a^*)$, can be determined as $P_a^*=0.4$ and $P_b^*=0.6$, even if increase of the customer demand by the green image from the remanufacturing activity is not expected, that is, $m=0$. This is the reason why when t_a is substantially smaller than t_b, the joint production of the component at the remanufacturing facility and the new production facility leads to the significant reduction of the inventory holding cost of the component in the system. As the result, this finally leads to increase of the system profit. From Tables 2-4, when the production time per unit of the recycled component t_a is not substantially smaller or is larger than the production time per unit of the new component t_b, the optimal production ratios, the optimal recycle ratio P_a^* and the optimal new production cost $P_a^*(=1-P_b^*)$, can be determined as $P_a^*=0$ and $P_b^*=1$, even if increase of the customer demand by the green image from the remanufacturing activity is not expected, that is, $m=0$.

Tables 1-4 also show the effect of increase of mean of the customer demand by the green image from the remanufacturing activity on the optimal policy in the system. From tables1-4, as the larger the value of m is from 0.1 to 0.8, the larger the value of the optimal recycle ratio P_a^* is. It implies that the joint production of the component at the remanufacturing facility and the new production facility leads to increase of the system profit if increase of the customer demand is expected as the green image factor from the remanufacturing activity, even when the recycle cost is higher than the new production cost. From Tables 1-4, as the value of the recycle ratio P_a is getting larger than the optimal value of the recycle ratio P_a^*, in some results the average value of the system profit in the case that $P_a > P_a^*$ is smaller than that in the case that the remanufacturing activity is not practiced, that is, $P_a^*=0$ and $P_b^*=1$. This is the reason why increment of the system cost incurred by the operation of the joint production in the case that $P_a > P_a^*$ is larger than increment of the system profit obtained from the operation of the joint production in this case.

[2] the effect of reduction of the recycle cost as to the recycle ratio on the production policy in the closed-loop supply chain system

Table 5 shows that results of the optimal production policy obtained from the following numerical example 1 : t_p =1/2000, t_a =1/1000, t_b =1/100.

Table 6 shows that results of the optimal production policy obtained from the following numerical example 2 : t_p =1/2000, t_a =1/1000, t_b =1/500.

Table 7 shows that results of the optimal production policy obtained from the following numerical example 3 : t_p =1/2000, t_a =1/100, t_b =1/1000.

Table 8 shows that results of the optimal production policy obtained from the following numerical example 4 : t_p =1/2000, t_a =1/500, t_b =1/1000.

Tables 5-8 show that the optimal production ratios, the optimal recycle ratio P_a^* and the optimal new production ratio $P_b^*(=1-P_a^*)$, the maximal average value of the system profit and the average value of the inventory holding cost of the component with consideration of reduction of the recycle cost $C_a(P_a)$ as to the recycle ratio obtained from equations (3)-(5) as shown figure 1 in addition to the increasing ratio of the customer demand m ($0 \le m \le 0.8$) for various values of the production time per unit of the final product t_p, the production time per unit of the recycled component t_a and the production time per unit of the new component t_b. Each value of the optimal recycle ratio P_a^* shown in Tables 5-8 indicates the minimal value of the recycle ratio P_a in the situation where the average value of the system profit with the joint production in the case that $P_a > 0$ is higher than that with the new production only in the case that $P_a = 0$ and $P_b = 1$.

Table 1 Optimal production policy with considerations of increase of the customer demand expected as green image factor from the remanufacturing activity (numerical example 1 : t_p =1/2000, t_a =1/1000, t_b =1/100)

P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	10	18932	1295793	0.0	1000	4500	3500
P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0.4	0.6	2	1	6	151993	762566	0.0	1000	4500	3500
0.5	0.5	2	1	6	199505	716352	0.1	1050	4500	3500
0.6	0.4	2	1	5	308208	634581	0.2	1120	4500	3500
0.7	0.3	2	1	4	424646	567637	0.3	1210	4500	3500
0.7	0.3	2	1	4	549760	568057	0.4	1280	4500	3500
0.7	0.3	2	1	5	647514	595883	0.5	1350	4500	3500
0.7	0.3	2	1	5	772347	596583	0.6	1420	4500	3500
0.6	0.4	2	1	6	835076	675907	0.7	1420	4500	3500
0.9	0.1	2	2	2	963693	590852	0.8	1720	4500	3500

Table 2 Optimal production policy with considerations of increase of the customer demand expected as green image factor from the remanufacturing activity (numerical example 2 : t_p =1/2000, t_a =1/1000, t_b =1/500)

P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	2	718892	587629	0.0	1000	4500	3500
P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	2	718892	587629	0.0	1000	4500	3500
0	1	2	0	2	718892	587629	0.1	1000	4500	3500
0	1	2	0	2	718892	587629	0.2	1000	4500	3500
0	1	2	0	2	718892	587629	0.3	1000	4500	3500
0.2	0.8	2	1	2	724209	566110	0.4	1080	4500	3500

0.4	0.6	2	1	2	786271	542585	0.5	1200	4500	3500
0.7	0.3	2	1	1	892315	476641	0.6	1420	4500	3500
0.6	0.4	2	1	2	986893	521239	0.7	1420	4500	3500
0.6	0.4	2	1	2	1100413	521319	0.8	1480	4500	3500

Table 3 Optimal production policy with considerations of increase of the customer demand expected as green image factor from the remanufacturing activity (numerical example 3 : t_p =1/2000, t_a =1/100, t_b =1/1000)

P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	1	840400.97	475781	0.0	1000	4500	3500
P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	1	840401	475781	0.0	1000	4500	3500
0	1	2	0	1	840401	475781	0.1	1000	4500	3500
0	1	2	0	1	840401	475781	0.2	1000	4500	3500
0	1	2	0	1	840401	475781	0.3	1000	4500	3500
0	1	2	0	1	840401	475781	0.4	1000	4500	3500
0.1	0.9	2	2	1	843871	487770	0.5	1050	4500	3500
0.2	0.8	2	3	1	871045	517948	0.6	1120	4500	3500
0.2	0.8	2	3	1	916872	517988	0.7	1140	4500	3500
0.3	0.7	2	4	1	972196	568017	0.8	1240	4500	3500

Table 4 Optimal production policy with considerations of increase of the customer demand expected as green image factor from the remanufacturing activity (numerical example 4 : t_p =1/2000, t_a =1/500, t_b =1/1000)

P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	1	840401	475781	0.0	1000	4500	3500
P_a^*	P_b^*	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	1	840401	475781	0.0	1000	4500	3500
0	1	2	0	1	840401	475781	0.1	1000	4500	3500
0	1	2	0	1	840401	475781	0.2	1000	4500	3500
0	1	2	0	1	840401	475781	0.3	1000	4500	3500
0	1	2	0	1	840401	475781	0.4	1000	4500	3500
0.2	0.8	2	1	1	866576	476666	0.5	1100	4500	3500
0.4	0.6	2	1	1	940627	476666	0.6	1240	4500	3500
0.3	0.7	2	1	1	997958	476652	0.7	1210	4500	3500
0.5	0.5	2	2	1	1076544	532114	0.8	1400	4500	3500

Table 5 Optimal production policy with considerations of both reduction of the recycle cost expected as to the recycle ratio and increase of the customer demand expected as the green image factor from the remanufacturing activity (numerical example 5 : $t_p = 1/2000$, $t_a = 1/1000$, $t_b = 1/100$)

System model with only manufacturing	P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
	0	1	2	0	10	18932	1295793	0.0	1000	4500	3500
System model with joint manufacturing and remanufacturing	P_a^*	P_b^*	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
Reduction pattern 1 of remanufacturing cost	0.2	0.8	2	1	8	157382	995269	0.0	1000	4300	3500
	0.2	0.8	2	1	9	133724	1065687	0.1	1020	4300	3500
	0.2	0.8	2	1	9	178470	1067607	0.2	1040	4300	3500
	0.2	0.8	2	1	9	223217	1069527	0.3	1060	4300	3500
	0.1	0.9	2	1	10	96564	1221555	0.4	1040	4400	3500
Reduction pattern 2 of remanufacturing cost	0.2	0.8	2	1	8	189274	995269	0.0	1000	4140	3500
	0.2	0.8	2	1	9	166256	1065687	0.1	1020	4140	3500
	0.1	0.9	2	1	10	60367	1218855	0.2	1020	4310	3500
Reduction pattern 3 of remanufacturing cost	0.2	0.8	2	1	8	125490	995269	0.0	1000	4460	3500
	0.1	0.9	2	1	10	19435	1217505	0.1	1010	4490	3500

Table 6 Optimal production policy with considerations of both reduction of the recycle cost expected as to the recycle ratio and increase of the customer demand expected as the green image factor from the remanufacturing activity (numerical example 6 : $t_p = 1/2000$, $t_a = 1/1000$, $t_b = 1/500$)

System model with only manufacturing	P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
	0	1	2	0	2	718892	587629	0.0	1000	4500	3500
System model with joint manufacturing and remanufacturing	P_a^*	P_b^*	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
Reduction pattern 1 of remanufacturing cost	0.9	0.1	2	1	1	746725	476652	0.0	1000	3600	3500
	0.6	0.4	2	1	1	732873	476666	0.1	1060	3900	3500
	0.5	0.5	2	1	2	754006	531614	0.2	1100	4100	3500
	0.2	0.8	2	1	2	720601	566057	0.3	1060	4300	3500
	0.1	0.9	2	1	2	733969	576983	0.4	1040	4400	3500
Reduction pattern 2 of remanufacturing cost	0.6	0.4	2	1	1	741067	476666	0.0	1000	3660	3500
	0.5	0.5	2	1	2	772512	531531	0.1	1050	3750	3500
	0.3	0.7	2	1	2	745908	555141	0.2	1060	3990	3500
	0.1	0.9	2	1	2	719209	576953	0.3	1030	4310	3500
Reduction pattern 3 of remanufacturing cost	1	0	2	1	0	840401	475781	0.0	1000	3500	3500
	0.8	0.2	2	1	1	726352	476666	0.1	1080	3860	3500
	0.7	0.3	2	1	1	779679	476641	0.2	1140	4010	3500
	0.5	0.5	2	1	2	723000	531698	0.3	1150	4250	3500
	0.1	0.9	2	1	2	724635	576983	0.4	1040	4490	3500

Table 7 Optimal production policy with considerations of both reduction of the recycle cost expected as to the recycle ratio and increase of the customer demand expected as the green image factor from the remanufacturing activity (numerical example 7 : t_p =1/2000, t_a =1/100, t_b =1/1000)

System model with only manufacturing	P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
System model with joint manufacturing and remanufacturing	P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
Reduction pattern 1 of remanufacturing cost	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
	0	1	2	0	1	840401	475781	0.1	1000	4500	3500
	0	1	2	0	1	840401	475781	0.2	1000	4500	3500
	0	1	2	0	1	840401	475781	0.3	1000	4500	3500
	0	1	2	0	1	840401	475781	0.4	1000	4500	3500
	0.1	0.9	2	2	1	854388	487770	0.5	1050	4400	3500
Reduction pattern 2 of remanufacturing cost	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
	0	1	2	0	1	840401	475781	0.1	1000	4500	3500
	0	1	2	0	1	840401	475781	0.2	1000	4500	3500
	0	1	2	0	1	840401	475781	0.3	1000	4500	3500
	0.2	0.8	2	3	1	856957	517868	0.4	1080	4140	3500
	0.1	0.9	2	2	1	863853	487770	0.5	1050	4310	3500
Reduction pattern 3 of remanufacturing cost	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
	0	1	2	0	1	840401	475781	0.1	1000	4500	3500
	0	1	2	0	1	840401	475781	0.2	1000	4500	3500
	0	1	2	0	1	840401	475781	0.3	1000	4500	3500
	0	1	2	0	1	840401	475781	0.4	1000	4500	3500
	0.1	0.9	2	2	1	844923	487770	0.5	1050	4490	3500

Table 8 Optimal production policy with considerations of both reduction of the recycle cost expected as to the recycle ratio and increase of the customer demand expected as the green image factor from the remanufacturing activity (numerical example 8 : t_p =1/2000, t_a =1/500, t_b =1/1000)

System model with only manufacturing	P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
System model with joint manufacturing and remanufacturing	P_a^*	P_b^*	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
Reduction pattern 1 of remanufacturing cost	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
	0.9	0.1	2	2	1	854088	577133	0.1	1090	3600	3500
	0.7	0.3	2	2	1	861214	555380	0.2	1140	3800	3500
	0.4	0.6	2	1	1	868001	476666	0.3	1120	4100	3500
	0.1	0.9	2	1	1	842518	476652	0.4	1040	4400	3500
	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
Reduction pattern 2 of remanufacturing cost	0.7	0.3	2	2	1	858319	555217	0.1	1070	3590	3500
	0.4	0.6	2	1	1	881173	476666	0.2	1080	3860	3500
	0.2	0.8	2	1	1	850954	476666	0.3	1060	4140	3500
	0.1	0.9	2	1	1	851872	476652	0.4	1040	4310	3500
	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
	1	0	2	3	0	873270	688186	0.1	1100	3500	3500
Reduction pattern 3 of remanufacturing cost	0.9	0.1	2	3	1	889246	668206	0.2	1180	3690	3500
	0.7	0.3	2	2	1	843529	555543	0.3	1210	4010	3500
	0.4	0.6	2	1	1	847170	542665	0.4	1160	4340	3500
	0.1	0.9	2	1	1	857107	476652	0.5	1050	4490	3500

In Tables 5-8, focusing on the case that increase of the customer demand as the green image factor from the remanufacturing activity is not expected, that is, $m = 0$, the effect of reduction of the recycle cost as to the recycle ratio on the optimal production policy is investigated. From Tables 5 and 6, when the production time per unit of the recycled component t_a is substantially smaller than the production time per unit of the new component t_b, by reduction of the recycle cost shown in equations (3)-(5) and figure 1, the average value of the system profit with the joint production in the case that $P_a > 0$ is higher than that with the new production only in that case that $P_a = 0$ and $P_b = 1$. This is the reason why when t_a is substantially smaller than t_b, the joint production of the component at the remanufacturing facility and the new production facility leads to the significant reduction of the inventory holding cost of the component in the system. As the result, this finally leads to increase of the system profit. In this situation, it would be easier to encourage the operation of the closed-loop supply chin system with the joint production of the remanufacturing and the new production, even if not only the recycle cost is higher than the new production cost, but also increase of the customer demand by the green image from the remanufacturing activity is not expected, that is, $m = 0$. On the other hand, from Tables 6-8, when the production time per unit of the recycled component t_a is not substantially smaller or is larger than the production time per unit of the new component t_b, the optimal production ratios, the optimal recycle ratio P_a^* and the optimal new production cost $P_b^* (= 1 - P_a^*)$, can be determined as $P_a^* = 0$ and $P_b^* = 1$, even if not only the difference between the recycle cost $C_a(P_a)$ and the new production cost C_b is substantially small or $C_a(P_a)$ is equal to C_b, but also increase of the customer demand by the green image from the remanufacturing activity is not expected, that is, $m = 0$.

[3] the effects of both increase of the customer demand expected as the green image factor from the remanufacturing activity and reduction of the recycle cost as to the recycle ratio on the production policy in the closed-loop supply chain system

From tables 5-8, as the value of the increasing ratio of the customer demand expected as the green image factor from the remanufacturing activity m is getting larger from 0.0 to 0.8, the optimal value of the recycle ratio P_a^* which is the minimal value of the recycle ratio in the situation where the average value of the system profit in the case that the remanufacturing activity is practiced, $P_a > 0$, is larger than that in the case that the only new production activity is performed, $P_a = 0$, is determined as a smaller value. The results imply that under the situation where both reduction of the recycle cost as to the recycle ratio and increase of the customer demand by the green image from the remanufacturing activity are expected, it would be easier to encourage the operation of the closed-loop supply chin system with the joint production of the remanufacturing and the new production.

[4] the relation between the remanufacturing lead time and the optimal recycle ratio

In tables 1-4, focusing on the value of the remanufacturing lead time L_a, the smaller the value of L_a is, the larger the value of the optimal recycle ratio P_a^* is. Under this situation, it would be easier to encourage the remanufacturing activity in the closed-loop supply chain system with the joint production of the remanufacturing and the new production. On the other hand, from equations (10) and (11), the larger the value of L_a is, the more the ordering quantity of the reusable material determined at the remanufacturing facility of the component increases. It causes increase of the on-hand inventory of the recycled component. This leads to increase of the inventory holding cost of the recycled component at the remanufacturing facility. If the production time per unit of the recycled component can be reduced, it would be easier to encourage the operation of the closed-loop supply chin system with the joint production of the remanufacturing and the new production.

By comparing the results in Tables 1-4 with those of Tables 5-8, it is evident that the improvement of the optimal recycle ratio obtained from reduction of the remanufacturing lead time L_a is smaller that that obtained from reduction of the recycle cost $C_a(P_a)$ as to the recycle ratio P_a. It is also evident from Tables 1-4 and Tables 5-8 that reduction of the remanufacturing lead time L_a influenced especially reduction of the on-hand inventory of the recycled component in the remanufacturing facility. As results obtained from Tables 1-8, if the recycle cost $C_a(P_a)$ can be reduced as so the recycle ratio P_a, it would be easier to encourage the operation of the closed-loop supply chin system with the joint production of the remanufacturing and the new production.

CONCLUSIONS

In this paper, we discussed a production planning in the closed-loop supply chain system which consisted of a manufacturing facility to produce a final product, a remanufacturing facility to produce a recycled component and a new production facility to produce a new component. Under the situation where the recycle cost of the component is more expensive than the new production cost of it, in order to investigate the effect of the remanufacturing activity on the production policy in the closed-loop supply chain system, reduction of the recycle cost as to the recycle ratio and increase of the customer demand expected as the effect of the green image factor from the remanufacturing activity were focus on here. By considering the balance of reduction of the recycle cost as to the production quantity of the recycled component and increase of the customer demand expected as the green image factor from the remanufacturing activity of the enterprise, the optimal production policy in the closed-loop supply chain system was discussed from the aspect of inventory management. Concretely, so as to maximize the profit in the closed-loop supply chain system, the optimal production ratios of the component at the remanufacturing facility and the new production facility were determined based on the periodic ordering system in inventory management. In numerical examples, impacts of both the green image factor expected by the remanufacturing activity and reduction of the recycle cost as to the recycle ratio on the production policy in the closed-loop supply chain system were demonstrated as the motivation to encourage the remanufacturing activity in the system.

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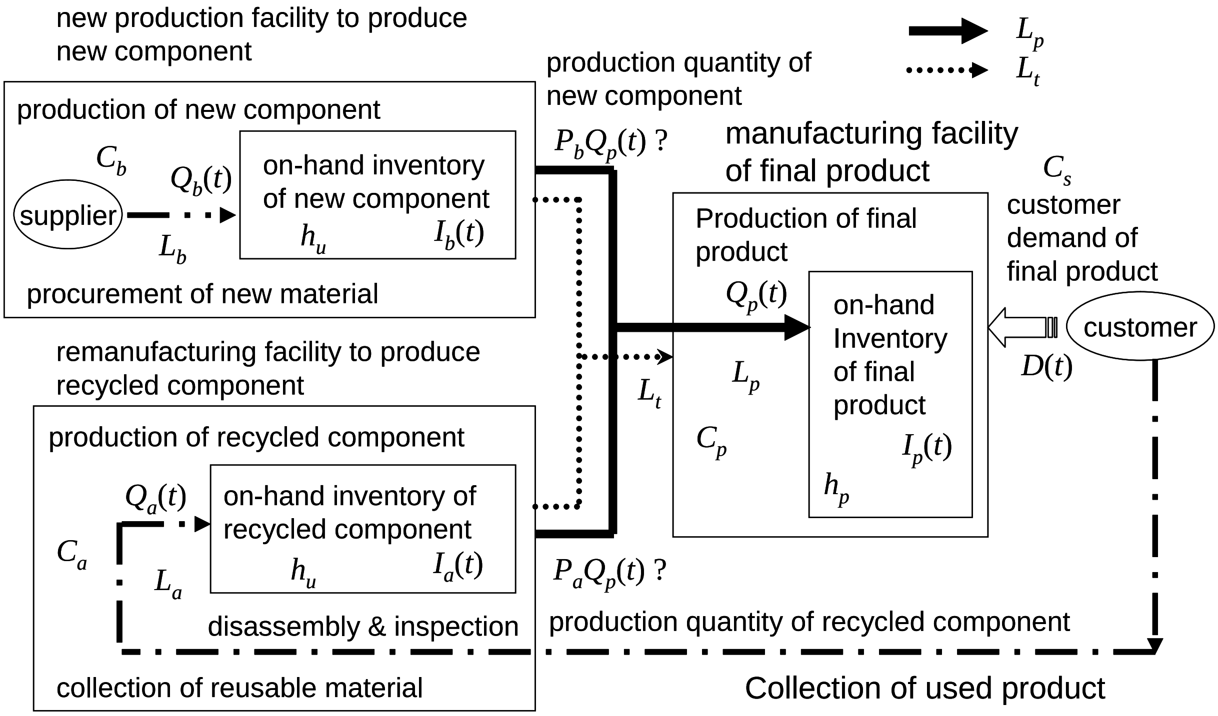
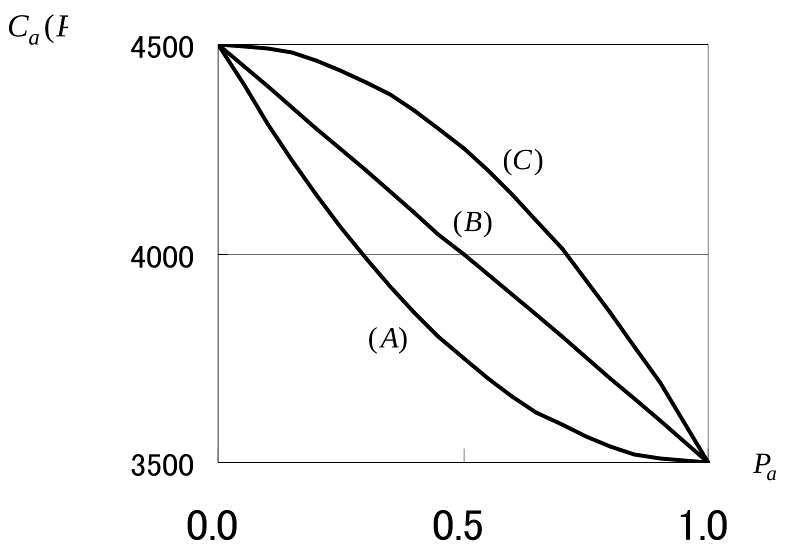


Figure 1 A closed-loop supply chain system



(A) $C_a(P_a) = (C_b - C_a(0))P_a + C_a(0)$

(B) $C_a(P_a) = (C_a(0) - C_b)(P_a - 1)^2 + C_b$

(C) $C_a(P_a) = (C_b - C_a(0))P_a^{\,2} + C_a(0)$

Figure 2 Decreasing functions to demonstrate reduction pattern of recycle cost for P_a

Table 1 Optimal production policy with considerations of increase of the customer demand expected as green image factor from the remanufacturing activity (numerical example 1 : t_p =1/2000, t_a =1/1000, t_b =1/100)

P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	10	18932	1295793	0.0	1000	4500	3500
P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0.4	0.6	2	1	6	151993	762566	0.0	1000	4500	3500
0.5	0.5	2	1	6	199505	716352	0.1	1050	4500	3500
0.6	0.4	2	1	5	308208	634581	0.2	1120	4500	3500
0.7	0.3	2	1	4	424646	567637	0.3	1210	4500	3500
0.7	0.3	2	1	4	549760	568057	0.4	1280	4500	3500
0.7	0.3	2	1	5	647514	595883	0.5	1350	4500	3500
0.7	0.3	2	1	5	772347	596583	0.6	1420	4500	3500
0.6	0.4	2	1	6	835076	675907	0.7	1420	4500	3500
0.9	0.1	2	2	2	963693	590852	0.8	1720	4500	3500

Table 2 Optimal production policy with considerations of increase of the customer demand expected as green image factor from the remanufacturing activity (numerical example 2 : t_p =1/2000, t_a =1/1000, t_b =1/500)

P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	2	718892	587629	0.0	1000	4500	3500
P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	2	718892	587629	0.0	1000	4500	3500
0	1	2	0	2	718892	587629	0.1	1000	4500	3500
0	1	2	0	2	718892	587629	0.2	1000	4500	3500
0	1	2	0	2	718892	587629	0.3	1000	4500	3500
0.2	0.8	2	1	2	724209	566110	0.4	1080	4500	3500
0.4	0.6	2	1	2	786271	542585	0.5	1200	4500	3500
0.7	0.3	2	1	1	892315	476641	0.6	1420	4500	3500
0.6	0.4	2	1	2	986893	521239	0.7	1420	4500	3500
0.6	0.4	2	1	2	1100413	521319	0.8	1480	4500	3500

Table 3 Optimal production policy with considerations of increase of the customer demand expected as green image factor from the remanufacturing activity (numerical example 3 : t_p =1/2000, t_a =1/100, t_b =1/1000)

P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	1	840400.97	475781	0.0	1000	4500	3500
P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	1	840401	475781	0.0	1000	4500	3500
0	1	2	0	1	840401	475781	0.1	1000	4500	3500
0	1	2	0	1	840401	475781	0.2	1000	4500	3500
0	1	2	0	1	840401	475781	0.3	1000	4500	3500
0	1	2	0	1	840401	475781	0.4	1000	4500	3500
0.1	0.9	2	2	1	843871	487770	0.5	1050	4500	3500
0.2	0.8	2	3	1	871045	517948	0.6	1120	4500	3500
0.2	0.8	2	3	1	916872	517988	0.7	1140	4500	3500
0.3	0.7	2	4	1	972196	568017	0.8	1240	4500	3500

Table 4 Optimal production policy with considerations of increase of the customer demand expected as green image factor from the remanufacturing activity (numerical example 4 : t_p =1/2000, t_a =1/500, t_b =1/1000)

P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	1	840401	475781	0.0	1000	4500	3500
P_a^*	P_b^*	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
0	1	2	0	1	840401	475781	0.0	1000	4500	3500
0	1	2	0	1	840401	475781	0.1	1000	4500	3500
0	1	2	0	1	840401	475781	0.2	1000	4500	3500
0	1	2	0	1	840401	475781	0.3	1000	4500	3500
0	1	2	0	1	840401	475781	0.4	1000	4500	3500
0.2	0.8	2	1	1	866576	476666	0.5	1100	4500	3500
0.4	0.6	2	1	1	940627	476666	0.6	1240	4500	3500
0.3	0.7	2	1	1	997958	476652	0.7	1210	4500	3500
0.5	0.5	2	2	1	1076544	532114	0.8	1400	4500	3500

Table 5 Optimal production policy with considerations of both reduction of the recycle cost expected as to the recycle ratio and increase of the customer demand expected as the green image factor from the remanufacturing activity (numerical example 5 : $t_p=1/2000$, $t_a=1/1000$, $t_b=1/100$)

System model with only manufacturing	P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
	0	1	2	0	10	18932	1295793	0.0	1000	4500	3500
System model with joint manufacturing and remanufacturing	P_a^*	P_b^*	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
Reduction pattern 1 of remanufacturing cost	0.2	0.8	2	1	8	157382	995269	0.0	1000	4300	3500
	0.2	0.8	2	1	9	133724	1065687	0.1	1020	4300	3500
	0.2	0.8	2	1	9	178470	1067607	0.2	1040	4300	3500
	0.2	0.8	2	1	9	223217	1069527	0.3	1060	4300	3500
	0.1	0.9	2	1	10	96564	1221555	0.4	1040	4400	3500
Reduction pattern 2 of remanufacturing cost	0.2	0.8	2	1	8	189274	995269	0.0	1000	4140	3500
	0.2	0.8	2	1	9	166256	1065687	0.1	1020	4140	3500
	0.1	0.9	2	1	10	60367	1218855	0.2	1020	4310	3500
Reduction pattern 3 of remanufacturing cost	0.2	0.8	2	1	8	125490	995269	0.0	1000	4460	3500
	0.1	0.9	2	1	10	19435	1217505	0.1	1010	4490	3500

Table 6 Optimal production policy with considerations of both reduction of the recycle cost expected as to the recycle ratio and increase of the customer demand expected as the green image factor from the remanufacturing activity (numerical example 6 : $t_p=1/2000$, $t_a=1/1000$, $t_b=1/500$)

System model with only manufacturing	P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
	0	1	2	0	2	718892	587629	0.0	1000	4500	3500
System model with joint manufacturing and remanufacturing	P_a^*	P_b^*	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
Reduction pattern 1 of remanufacturing cost	0.9	0.1	2	1	1	746725	476652	0.0	1000	3600	3500
	0.6	0.4	2	1	1	732873	476666	0.1	1060	3900	3500
	0.5	0.5	2	1	2	754006	531614	0.2	1100	4100	3500
	0.2	0.8	2	1	2	720601	566057	0.3	1060	4300	3500
	0.1	0.9	2	1	2	733969	576983	0.4	1040	4400	3500
Reduction pattern 2 of remanufacturing cost	0.6	0.4	2	1	1	741067	476666	0.0	1000	3660	3500
	0.5	0.5	2	1	2	772512	531531	0.1	1050	3750	3500
	0.3	0.7	2	1	2	745908	555141	0.2	1060	3990	3500
	0.1	0.9	2	1	2	719209	576953	0.3	1030	4310	3500
Reduction pattern 3 of remanufacturing cost	1	0	2	1	0	840401	475781	0.0	1000	3500	3500
	0.8	0.2	2	1	1	726352	476666	0.1	1080	3860	3500
	0.7	0.3	2	1	1	779679	476641	0.2	1140	4010	3500
	0.5	0.5	2	1	2	723000	531698	0.3	1150	4250	3500
	0.1	0.9	2	1	2	724635	576983	0.4	1040	4490	3500

Table 7 Optimal production policy with considerations of both reduction of the recycle cost expected as to the recycle ratio and increase of the customer demand expected as the green image factor from the remanufacturing activity (numerical example 7 : t_p =1/2000, t_a =1/100, t_b =1/1000)

System model with only manufacturing	P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
System model with joint manufacturing and remanufacturing	P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
Reduction pattern 1 of remanufacturing cost	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
	0	1	2	0	1	840401	475781	0.1	1000	4500	3500
	0	1	2	0	1	840401	475781	0.2	1000	4500	3500
	0	1	2	0	1	840401	475781	0.3	1000	4500	3500
	0	1	2	0	1	840401	475781	0.4	1000	4500	3500
	0.1	0.9	2	2	1	854388	487770	0.5	1050	4400	3500
Reduction pattern 2 of remanufacturing cost	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
	0	1	2	0	1	840401	475781	0.1	1000	4500	3500
	0	1	2	0	1	840401	475781	0.2	1000	4500	3500
	0	1	2	0	1	840401	475781	0.3	1000	4500	3500
	0.2	0.8	2	3	1	856957	517868	0.4	1080	4140	3500
	0.1	0.9	2	2	1	863853	487770	0.5	1050	4310	3500
Reduction pattern 3 of remanufacturing cost	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
	0	1	2	0	1	840401	475781	0.1	1000	4500	3500
	0	1	2	0	1	840401	475781	0.2	1000	4500	3500
	0	1	2	0	1	840401	475781	0.3	1000	4500	3500
	0	1	2	0	1	840401	475781	0.4	1000	4500	3500
	0.1	0.9	2	2	1	844923	487770	0.5	1050	4490	3500

Table 8 Optimal production policy with considerations of both reduction of the recycle cost expected as to the recycle ratio and increase of the customer demand expected as the green image factor from the remanufacturing activity (numerical example 8 : t_p =1/2000, t_a =1/500, t_b =1/1000)

System model with only manufacturing	P_a	P_b	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
System model with joint manufacturing and remanufacturing	P_a^*	P_b^*	L_p	L_a	L_b	Maximal average value of system profit	Average value of inventory holding costs of component	m	$\mu_D(P_a)$	$C_a(P_a)$	C_b
Reduction pattern 1 of remanufacturing cost	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
	0.9	0.1	2	2	1	854088	577133	0.1	1090	3600	3500
	0.7	0.3	2	2	1	861214	555380	0.2	1140	3800	3500
	0.4	0.6	2	1	1	868001	476666	0.3	1120	4100	3500
	0.1	0.9	2	1	1	842518	476652	0.4	1040	4400	3500
	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
Reduction pattern 2 of remanufacturing cost	0.7	0.3	2	2	1	858319	555217	0.1	1070	3590	3500
	0.4	0.6	2	1	1	881173	476666	0.2	1080	3860	3500
	0.2	0.8	2	1	1	850954	476666	0.3	1060	4140	3500
	0.1	0.9	2	1	1	851872	476652	0.4	1040	4310	3500
	0	1	2	0	1	840401	475781	0.0	1000	4500	3500
	1	0	2	3	0	873270	688186	0.1	1100	3500	3500
Reduction pattern 3 of remanufacturing cost	0.9	0.1	2	3	1	889246	668206	0.2	1180	3690	3500
	0.7	0.3	2	2	1	843529	555543	0.3	1210	4010	3500
	0.4	0.6	2	1	1	847170	542665	0.4	1160	4340	3500
	0.1	0.9	2	1	1	857107	476652	0.5	1050	4490	3500

A MODEL FOR CAPTURING THE EFFECTS OF MACROECONOMIC INDICATORS ON AGGREGATE PLANNING IN A SUPPLY NETWORK

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ABSTRACT

As competition in the global market is getting tougher, firms are turning to their supply networks in order to improve their competitiveness. This is done by improving the performance of some components of the supply network while not violating the requirements of the other components. This is undoubtedly a difficult task to achieve considering the autonomous nature of these units of the network and also their distributed topology. Within the last few years, firms have resulted into a globalization of their industrial workspace in order to put a lid on cost as well as harness the opportunities of new markets. The globalization of these workspaces however introduces new challenges to the supply chain of these firms in the form of impediments to trade across national borders. We present a model for estimating the effects of some of these macroeconomic indicators on a firms supply network. We define the supply network as a virtual enterprise network which has the ability of taking advantage of the technology provided by existing telecommunication networks including the internet, to conduct transactions and also provide for easy reconfiguration across enterprise boundaries. In this model, enterprise units are represented as trading agents operating within a competitive market structure to arrive at a pareto-allocation of resources in the network. We first describe a process of trading among the agents within a Walrasian market structure and then we consider the effects of two macroeconomic variables – per-capital income and interest rates – on the pareto-allocation of resources in the virtual enterprise network.

INTRODUCTION

A supply network which is integrated such that the various units in the network is weakly coupled together for easy re-configurability can be referred to as a virtual enterprise (VE) network [2, 5]. This coupling is made possible by Information and Communication Technology systems. The major advantage of representing a supply network as a VE network is that it assumes a very low information latency level and aids the development of decision support models for supply network management.

In our supply network model, we represent units in the global workspace of firms as trading agents and characterize the workspace as a Walrasian market in order to obtain optimal resource allocation at market clearing [3, 4, 16]. In previous works [3, 4, 6, 7], it has been shown how a set of trading agents operating in a competitive market environment will arrive at equilibrium after rounds of bidding in response to price changes in the market. The application of the Walrasian market structure to strategic planning of supply networks and the efficiency of our algorithm based on Market-Oriented Programming (MOP) is treated in [16]. We will briefly describe this model in the next section.

Our goal in this research work is to present a model that can be used in estimating the effects of macroeconomic indicators on a globalized supply network. While it may be obvious that a change in the value of any macroeconomic indicator in a country is likely to have an impact on a supply network which has one of its units resident in that country, it may not be clear how we can measure the impact of such an indicator in terms of some performance indicators in the supply network. We therefore construct a simple model based on reactive agents operating within a Walrasian market framework to capture these effects.

For the purpose of running our simulation, we make use of two macroeconomic indicators – per capita income (PCI) and interest rate (IR) in the economy and we investigate how these two parameters affect our experimental supply network. First, we run a simulation of the supply network without varying the macroeconomic parameters and then we run the simulation varying one parameter at a time. It is also possible to vary some other macroeconomic parameters as long as they can be well represented in the model. We discuss how the representations of per capita income and interest rate are done in our model. It should be noted however, that our goal is not to give a detailed description of the effects of macroeconomic indices in international trade but to propose a framework which allows us to investigate the effects they have on a given supply network which cuts across national boundaries.

In the next section, we briefly describe the concept of competitive market equilibrium in a multi-commodity market and how market forces of demand and supply lead to an equilibrium allocation of resources among a set of trading agents. We discuss the agents' constraint optimization problems which they solve to arrive at an optimal bid in response to current market prices. The collation of bids by the market mechanism and subsequent adjustment of prices of commodities in the market which leads to a search for competitive equilibrium in the market is also described. Mention is made of the Scarf algorithm and the price-tatonnement algorithm, the performances of which we have investigated in order to compare them with the MOP algorithm which we have used. In the following section, there is the description of our supply network model. We discuss how we remodel the supply network in to a competitive market made up of supply and demand agents. Subsequently, we present simulation procedures of the different simulations we have run. We discuss the results of the simulations in the following section. We present empirical results detailing the accuracy of result and speed of performance of the MOP algorithm. Also in this section, results on the effects of representative macroeconomic indicators on the supply network are discussed. In the last section, concluding remarks on the research work are made.

MARKET EQUILIBRIUM COMPUTATION

In microeconomics, the concept of computable general equilibrium is based on price variation in a competitive market. To date, a number of algorithms have been developed to search for an equilibrium price vector among a set of trading agents battering as price-takers in a market with multiple resources [1, 10, 11]. The common denominator among these algorithms is the assumption of profit maximization among the trading agents. It is also worthy of note that some of these algorithms have been extended by researchers in macroeconomics to model the effects of some policy decisions on the market economy structure [12, 13]. In our case, we are concerned first with improving on the efficiency of the existing algorithms and then employ the algorithm in resource allocation within a supply network.

The market-oriented programming (MOP) algorithm used makes use of the laws of welfare economics which guarantees that a Walrasian market will conduct a pareto-optimal allocation of resources among a set of trading agents in a price-taking market structure [16]. We present a definition of agents and briefly explain some results of the algorithm as compared with the price-tatonnement algorithm.

There are two types of trading agents defined in the Walrasian market as shown in figure 1. The consumer agents are endowed with market resources which the supplier agents need to produce their goods and the consumer agents have unique preferences for the various goods produced in the market. In order to get what they want, the consumer agents rent out their endowments to the supplier agents who in turn use their unique technologies to produce goods needed in the market. The competitive market structure demands that the consumers must rent out all their endowments to the suppliers while the suppliers will remit all the profits generated by them to the consumers. Also, all the goods produced in the market must be consumed by the consumer agents in the market. These conditions mean that the total amount of expenditure in the market must be equal to the total amount of revenue and also that the total amount of production must be matched by the total amount of consumption in the market; i.e. there is conservation of products and value in a competitive market. The prices of market resources determine the budget of each consumer agent, which is the total amount expendable by them. The price vector also affects the profits that accrue to the supplier agents. Next, we take a look at a formal definition of these trading agents and how the submit their bids to the market mechanism. The Cobb-Douglas function we use in our model is a special case of the Constant Elasticity of Substitution (CES) function in microeconomics and we assume constant returns to scale.

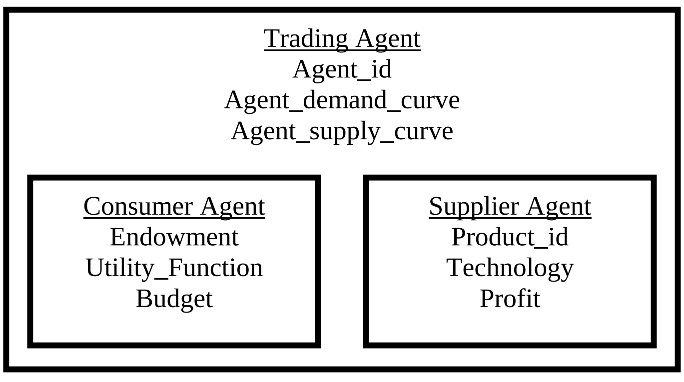

Figure 1: Trading Agent Class

Consumer Agent:

Given a set of *n* consumers and *m* suppliers in an economy with *k* goods, in order to bid for goods, the consumer solves the constrained optimization problem:

$$\max U^c(g_1, g_2, g_3, ..., g_k) \tag{1}$$

Where *U* (.) is utility function and we make use of Cobb-Douglas function with a constant returns to scale and is define as:

$$\max U^c = R_c \prod_{i=1}^{k} g_i^{\alpha_i^c} \tag{2}$$

Given that $\sum_{i=1}^{k} \alpha_i^c = 1$ for all 1 ≤ *c* ≤ *n* (3)

Where R_c = consumption scale of consumer *c*

α_i^c = preference index of consumer *c* of good *i*

p_i = price of good *i*

e_i^c = endowment of consumer *c* of good *i*

g_i^c = bid of good *i* by consumer *c*

Subject to a budget constraint given as:

$$\sum_{i}^{k} p_i g_i^c \le B^c \tag{4}$$

and a non-negative constraint

$$p_i \in P > 0 \ \forall \ 1 \le i \le k \tag{5}$$

Where $p_i \in P \ \forall \ i = 1,2,3,...,n$ is price of resource *i* and $e_i^c \in E \ \forall \ i = 1,2,3,...,n$ is the endowment of agent *c* on resource *i*.

Solving the constraint optimization problem the bidding function for a consumer agent is:

$$g_i^c(p_i) = \frac{\alpha_i^c * B^c}{p_i} \tag{6}$$

Supplier Agent:

A supplier agent also bids for goods in the economy by solving its constraint optimization problem. We again make use of the Cobb-Douglas Function to represent the supplier's technology function:

$$\max \pi^s(P) = p_s g_s - \sum_{\substack{i=1 \\ i \ne s}}^{k} p_i g_i^s \tag{7}$$

Subject to technology function

$$g_s(P) = R_s \prod_{\substack{i=1 \\ i \ne s}}^{k} g_i^{\beta_i^s} \tag{8}$$

Given that $\sum_{i=1}^{k} \beta_i^s = 1$ for all 1 ≤ *s* ≤ *m* (9)

Using same method as for the consumer agent problem, we derive the bidding function for a supplier agent as:

$$g_i^s(p_i) = \left(\frac{p_i}{R_s \beta_i^s p_s} \right)^{\frac{1}{\beta_i^s - 1}} \tag{10}$$

Where β_i^s = technology index of good *i* for agent *s*

Searching for Equilibrium

A number of computational methods can be used to solve the constraint optimization problems of equations (2) and (7) as long as the utility and technology functions are well-behaved, that is, each function is both monotonic and homogenous [14]. Price tatonnement algorithm and Scarf algorithm [10, 11] are popular methods used in solving for equilibrium price vector.

The price tatonnement algorithm was proposed by Leon Walras as a decentralized relaxation method based on conventional price adjustment. Prices of individual products are adjusted upward or downward depending on excess demand of that in the economy. The simple price adjustment formula used is:

$$P_{t+1} = P_t + \alpha\left(\sum_{i=1}^{n} x_i - \sum_{i=1}^{n} e_i\right) \tag{11}$$

Where α = price adjustment constant, x_i = market demand of product by trader *i* and e_i is market supply of product by trader *i*. The speed of convergence to equilibrium price and the accuracy of the results depend on how small the value of α is. The smaller the value of α, the slower the convergence but the higher the accuracy of the results.

Scarf Algorithm is based on the Fixed-point theorem. This algorithm uses a function *f*(.) to map a simplex (whose corners are price vectors) into itself. The mapping seeks to find a point in the geometric space in which all the corner points of the simplex gives a complete mapping of the price vector into the simplex. The number of divisions of the simplex determines both the accuracy of the results as well as the speed of convergence. The higher the number of divisions of the simplex, the higher the accuracy and the slower the speed of convergence. The existence of a unique equilibrium price p* requires monotonicity in the preferences of traders. This condition means that if the preferences of traders are revealed, the marginal rate of substitution (MRS) must be the same for all trading agents for market clearing to occur; i.e. $MRS_i = C \quad \forall\, 1 \le i \le k$ where *C* is a constant positive value.

Market Mechanism

Figure 2 illustrates the market mechanism. Operating under the axioms stated in the Walrasian market structure, all consumer agents supply all their endowments to the market. The suppliers make use of these endowments to produce goods which the consumers use to produce their utility. Going by the conservation of value axiom, all the profits made by the suppliers are returned to the consumers.

Current prices of goods in the market are displayed on the blackboard and agents compute their bids based on the price vector. The bids are submitted to the market mechanism which computes the total demand and supply for each good and also finds the equilibrium prices for the commodities. It posts the new price vector on the blackboard and agents react to this new information by computing new bids and sending them to the market mechanism. This process continues until no agent is willing to change its bid any longer. At this point, market is said to clear and a Pareto allocation of goods is achieved. Figure 3 shows a simple flowchart describing this process.

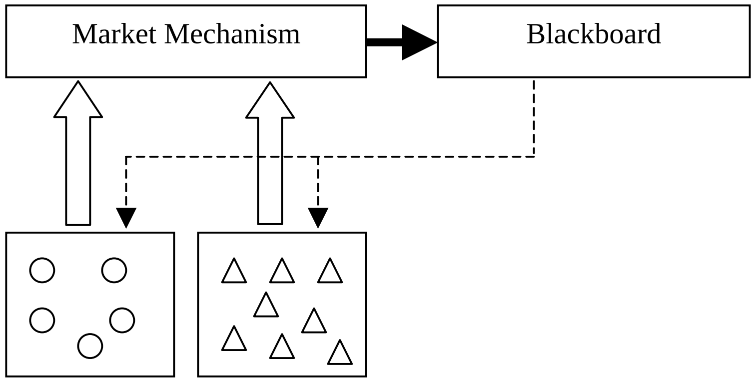

Figure 2: Blackboard Architecture for Competitive market

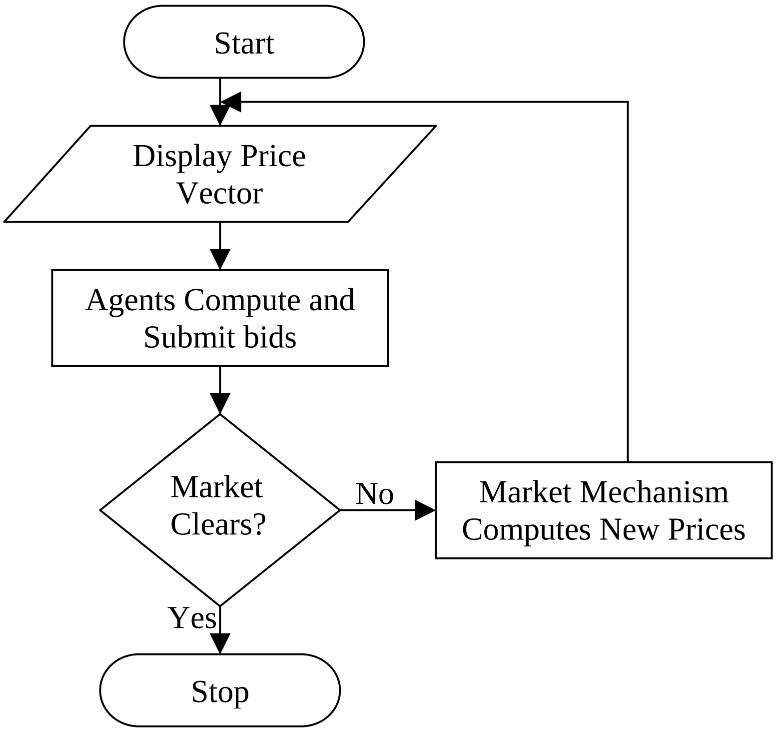

Figure 3: Trading Protocol

SUPPLY NETWORK MODEL

In our multi-layer supply network model, we make use of the assumptions in Walrasian market model to construct our market mechanism. We remodel or VE network to take the form of a competitive market. Each of the agents in the supply network represents facilities in the value-addition process. The facilities are characterized by two functional attributes: purchasing of input resources subject to the budget constraint of that particular facility and using the inputs to produce goods which are consumed in the succeeding layer of the network. Production in a facility is also subject to the facility’s technology constraint.

Supply Network Topology

Figure 4 shows our four-layer VE network and figure 5 shows the network after it has been restructured into a competitive market. The C layer of the VE network is made up of pure consumers while the SS to the P layers are made up of suppliers. Each agent in these supplier layers is made up of a purchasing section and a production section. The purchasing section of a supplier agent becomes a neo-consumer in the Walrasian market while the production section is responsible for supplying goods into the market.

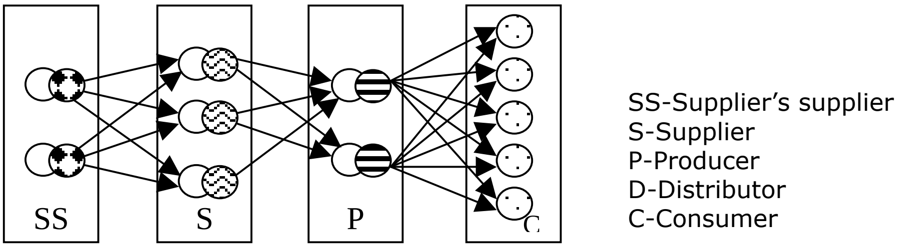

Figure 4: A Four-layer VE Network

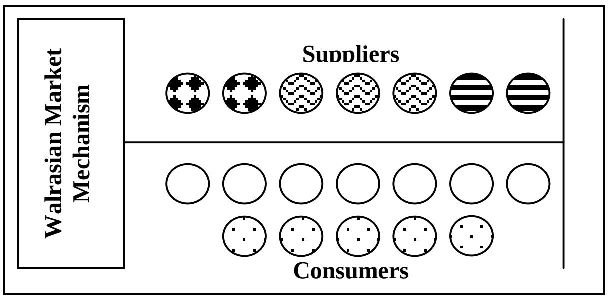

Figure 5: Walrasian Market Model

Trading Agent Parameters

In all, we have nineteen trading agents in our virtual market – seven suppliers, seven neo-consumers and five pure consumers. Table 1 shows supplier agent parameters and Table 2 shows the parameters of pure consumers:

We designate the output of each supplier as intermediate goods and capital and labour as primary factors in the economy. The output commodities of the P layer, we regard as the final product of the supply network to be consumed by the pure consumers. Using the parameters in tables 1 and 2 we ran simulations based on our model and also based on the tatonnement algorithm proposed by Leon Walras. We went a step further in creating a dynamic scenario for our model by gradually increasing the number of trading agents and inspecting the performance of the algorithm in terms of computational speed.

The data presented here are purely hypothetical data and are random values used solely for the purpose of representing agent parameters. The first set of tables show both the investment and technology sides of each of the supplier agents and the second set of tables represents the parameters for the pure consumers.

	Supplier's Supplier(ss1)			
	Investment		Technology	
	Pref.	Endow.	Scale	Index
Good 1(ss1)	0	0	0	0
Good 2(ss2)	0	0	0	0
Good 3(s1)	0	0	0	0
Good 4(s2)	0	0	0	0
Good 5(s3)	0	0	0	0
Good 6(m1)	0	0	0	0
Good 7(m2)	0	0	0	0
Capital	0	0	25	0.2
Labour	0	0	47	0.8

	Supplier's Supplier(ss2)			
	Investment		Technology	
	Pref.	Endow.	Scale	Index
Good 1(ss1)	0	0	0	0
Good 2(ss2)	0	0	0	0
Good 3(s1)	0	0	0	0
Good 4(s2)	0	0	0	0
Good 5(s3)	0	0	0	0
Good 6(m1)	0	0	0	0
Good 7(m2)	0	0	0	0
Capital	0	0	74	0.7
Labour	0	0	23	0.3

	Supplier(s1)			
	Investment		Technology	
	Pref.	Endow.	Scale	Index
Good 1(ss1)	0	0	25	0.3
Good 2(ss2)	0	0	23	0.3
Good 3(s1)	0	0	0	0
Good 4(s2)	0	0	0	0
Good 5(s3)	0	0	0	0
Good 6(m1)	0	0	0	0
Good 7(m2)	0	0	0	0
Capital	0.65	50	70	0.25
Labour	0.35	30	40	0.15

	Supplier(s2)			
	Investment		Technology	
	Pref.	Endow.	Scale	Index
Good 1(ss1)	0	0	40	0.4
Good 2(ss2)	0	0	30	0.1
Good 3(s1)	0	0	0	0
Good 4(s2)	0	0	0	0
Good 5(s3)	0	0	0	0
Good 6(m1)	0	0	0	0
Good 7(m2)	0	0	0	0
Capital	0.7	40	60	0.2
Labour	0.3	60	34	0.3

	Supplier(s3)			
	Investment		Technology	
	Pref.	Endow.	Scale	Index
Good 1(ss1)	0	0	60	0.2
Good 2(ss2)	0	0	10	0.4
Good 3(s1)	0	0	0	0
Good 4(s2)	0	0	0	0
Good 5(s3)	0	0	0	0
Good 6(m1)	0	0	0	0
Good 7(m2)	0	0	0	0
Capital	0.8	60	37	0.3
Labour	0.2	40	49	0.1

	Producer(m1)			
	Investment		Technology	
	Pref.	Endow.	Scale	Index
Good 1(ss1)	0	0	0	0
Good 2(ss2)	0	0	0	0
Good 3(s1)	0	0	35	0.15
Good 4(s2)	0	0	65	0.34
Good 5(s3)	0	0	40	0.26
Good 6(m1)	0	0	0	0
Good 7(m2)	0	0	0	0
Capital	0.75	250	63	0.2
Labour	0.25	30	51	0.05

	Producer(m2)			
	Investment		Technology	
	Pref.	Endow.	Scale	Index
Good 1(ss1)	0	0	0	0
Good 2(ss2)	0	0	0	0
Good 3(s1)	0	0	43	0.26
Good 4(s2)	0	0	57	0.34
Good 5(s3)	0	0	0	0
Good 6(m1)	0	0	0	0
Good 7(m2)	0	0	0	0
Capital	0.85	150	49	0.17
Labour	0.15	40	47	0.23

Pref. – Preference Index
Endow. – Endowment
Scale – Returns to scale
Index – Technology index

Table 1: Parameters of Supplier Agents

Preference Indices of Pure Consumers					
	Consumer (C8)	**Consumer (C9)**	**Consumer C(10)**	**Consumer (C11)**	**Consumer (C12)**
Good 1(ss1)	0	0	0	0	0
Good 2(ss2)	0	0	0	0	0
Good 3(s1)	0	0	0	0	0
Good 4(s2)	0	0	0	0	0
Good 5(s3)	0	0	0	0	0
Good 6(m1)	0.2	0.25	0.34	0.11	0.37
Good 7(m2)	0.8	0.75	0.66	0.89	0.63
Capital	0	0	0	0	0
Labour	0	0	0	0	0

Table 2(a): Preference Indices of Pure Consumers

Endowment of Pure Consumers					
	Consumer (C8)	**Consumer (C9)**	**Consumer C(10)**	**Consumer (C11)**	**Consumer (C12)**
Good 1(ss1)	0	0	0	0	0
Good 2(ss2)	0	0	0	0	0
Good 3(s1)	0	0	0	0	0
Good 4(s2)	0	0	0	0	0
Good 5(s3)	0	0	0	0	0
Good 6(m1)	0	0	0	0	0
Good 7(m2)	0	0	0	0	0
Capital	110	70	80	100	9
Labour	300	150	160	70	12

Table 2(b): Endowments of Pure Consumers

Resource Allocation Table

After running simulation based on the above data, we got the results presented in the tables below showing the distribution of market resources among all the trading agents in the market. Tables 3(a-b) show the demand and supply schedules of producer agents while tables 3(c-e) reveal those of the consumer agents. It must be noted that the first seven consumers in the market are defined as neo-consumers which are the purchasing section of the manufacturing agents in the initial supply network model. Consumers 8 – 12 are the pure consumers in the market who demand the final goods 6 and 7.

	Supplier's Supplier(ss1)		Supplier's Supplier(ss2)		Supplier(s1)	
	Demand	Supply	Demand	Supply	Demand	Supply
Good 1(ss1)	0	3363.2528	0	0	190.986	0
Good 2(ss2)	0	0	0	254.1115	176.0927	0
Good 3(s1)	0	0	0	0	0	377.2305
Good 4(s2)	0	0	0	0	0	0
Good 5(s3)	0	0	0	0	0	0
Good 6(m1)	0	0	0	0	0	0
Good 7(m2)	0	0	0	0	0	0
Capital	0.1036992	0	5.26622603	0	4.342809	0
Labour	206.89802	0	0.39197699	0	2.858787	0

Table 3(a): Resource Allocation for Agents SS1 – S1

	Supplier(s2)		Supplier(s3)		Manufacturer(m1)		Manufacturer(m2)	
	Demand	Supply	Demand	Supply	Demand	Supply	Demand	Supply
Good 1(ss1)	3117.766	0	66.97896	0	0	0	0	0
Good 2(ss2)	34.21873	0	45.56163	0	0	0	0	0
Good 3(s1)	0	0	0	0	23.16697	0	353.1167	0
Good 4(s2)	0	1195.158	0	0	278.7341	0	912.7275	0
Good 5(s3)	0	0	0	268.5653	268.2198	0	0	0
Good 6(m1)	0	0	0	0	0	820.4578	0	0
Good 7(m2)	0	0	0	0	0	0	0	984.6557
Capital	4.038983	0	0.822358	0	9.32288	0	15.71551	0
Labour	13.39015	0	0.902099	0	3.020852	0	83.687	0

Table 3(b): Resource Allocation for Agents S2 – M2

	Consumer (C1)		Consumer (C2)		Consumer (C3)		Consumer (C4)	
	Demand	Supply	Demand	Supply	Demand	Supply	Demand	Supply
Good 1(ss1)	0	0	0	0	0	0	0	0
Good 2(ss2)	0	0	0	0	0	0	0	0
Good 3(s1)	0	0	0	0	0	0	0	0
Good 4(s2)	0	0	0	0	0	0	0	0
Good 5(s3)	0	0	0	0	0	0	0	0
Good 6(m1)	0	0	0	0	0	0	0	0
Good 7(m2)	0	0	0	0	0	0	0	0
Capital	0	0	0	0	80.36825	50	90.2833	40
Labour	0	0	0	0	102.3607	30	91.477	60

Table 3(c): Resource Allocation for Agents C1 – C4

	Consumer (C5)		Consumer (C6)		Consumer (C7)		Consumer (C8)	
	Demand	Supply	Demand	Supply	Demand	Supply	Demand	Supply
Good 1(ss1)	0	0	0	0	0	0	0	0
Good 2(ss2)	0	0	0	0	0	0	0	0
Good 3(s1)	0	0	0	0	0	0	0	0
Good 4(s2)	0	0	0	0	0	0	0	0
Good 5(s3)	0	0	0	0	0	0	0	0
Good 6(m1)	0	0	0	0	0	0	197.0661	0
Good 7(m2)	0	0	0	0	0	0	315.8526	0
Capital	121.3698	60	388.5095	250	279.8017	150	0	110
Labour	71.76702	40	306.4442	30	116.8242	40	0	300

Table 3(d): Resource Allocation for Agents C5 – C8

	Consumer (C9)		Consumer (C10)		Consumer (C11)		Consumer (C12)	
	Demand	Supply	Demand	Supply	Demand	Supply	Demand	Supply
Good 1(ss1)	0	0	0	0	0	0	0	0
Good 2(ss2)	0	0	0	0	0	0	0	0
Good 3(s1)	0	0	0	0	0	0	0	0
Good 4(s2)	0	0	0	0	0	0	0	0
Good 5(s3)	0	0	0	0	0	0	0	0
Good 6(m1)	138.7682	0	208.8509	0	59.30935	0	216.641	0
Good 7(m2)	166.8107	0	162.4478	0	192.2795	0	147.806	0
Capital	0	70	0	80	0	100	0	90
Labour	0	150	0	160	0	70	0	120

Table 3(e): Resource Allocation for Agents C9 – C12

The first simulation run was done assuming a stable macroeconomic environment and we got results as follows: Figure 6 shows how prices fluctuate during bidding and figures 7(a-i) depicts variation of demand and supply for the commodities during the search for market clearing. While figure 6 illustrates how the market mechanism posts new prices to arrive at market clearing, figures 7(a-i) reveal how the demand and supply bids of trading agents move to converge at a market clearing point. The market is said to clear after demands and supplies for all the resources in the market converge. We use the results from the simulation to confirm that our model conducts pareto-optimality among a set of trading agents. Figure 7(j) illustrates the coincidence of demand and supply for all the resources in the market.

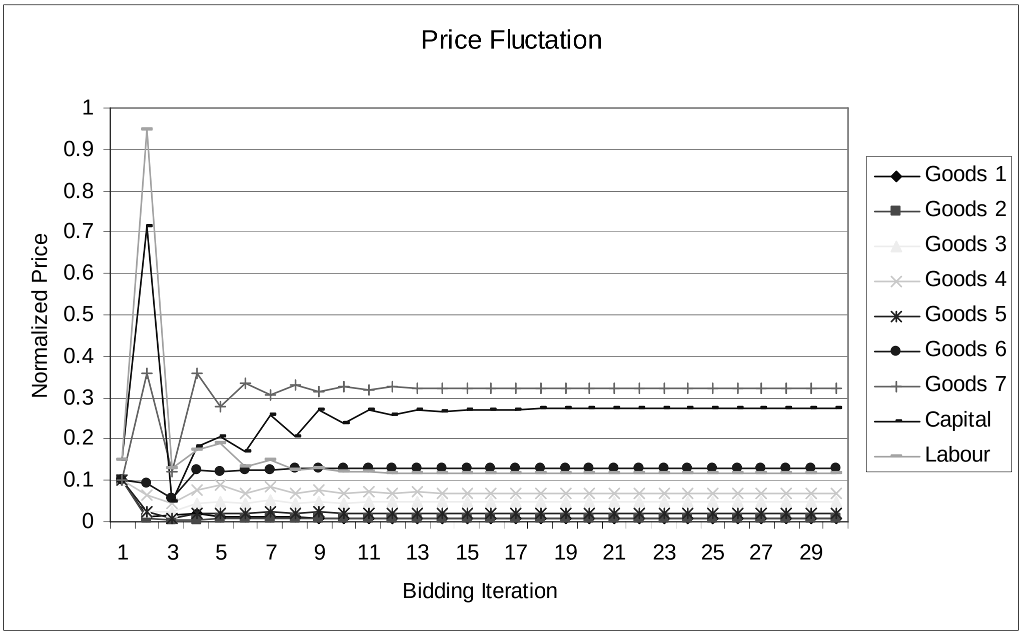

Figure 6: Price Fluctuation for all Commodities during Bidding

The equilibrium price vector is shown in table 4 below:

Goods 1	Goods 2	Goods 3	Goods 4	Goods 5	Goods 6	Goods 7	Capital	Labour
0.008967	0.008706	0.047089	0.069832	0.021521	0.129775	0.323666	0.273355	0.115856

Table 4: Equilibrium Price Vector

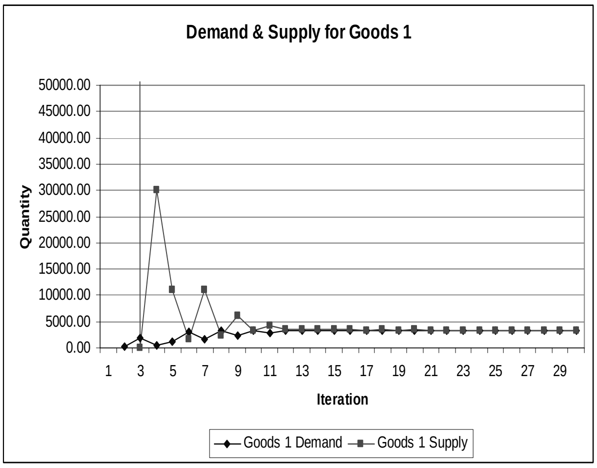

Figure 7(a): Demand and Supply Fluctuation for Goods1

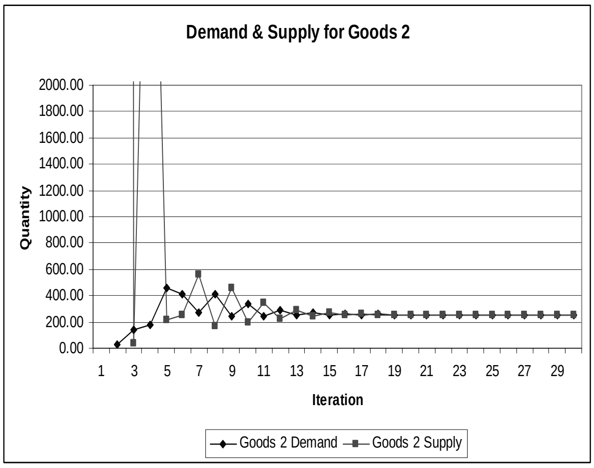

Figure 7(b): Demand and Supply Fluctuation for Goods2

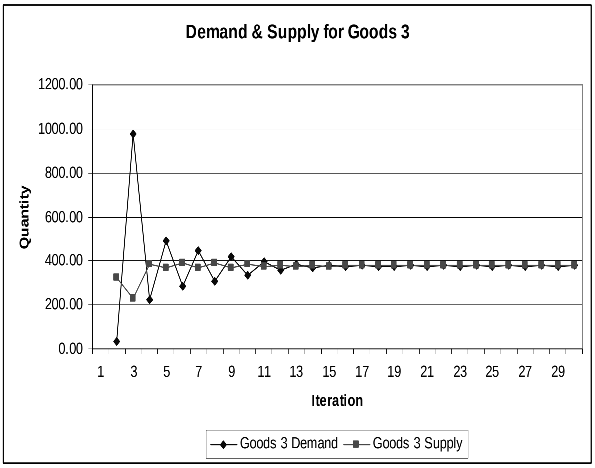

Figure 7(c): Demand and Supply Fluctuation for Goods3

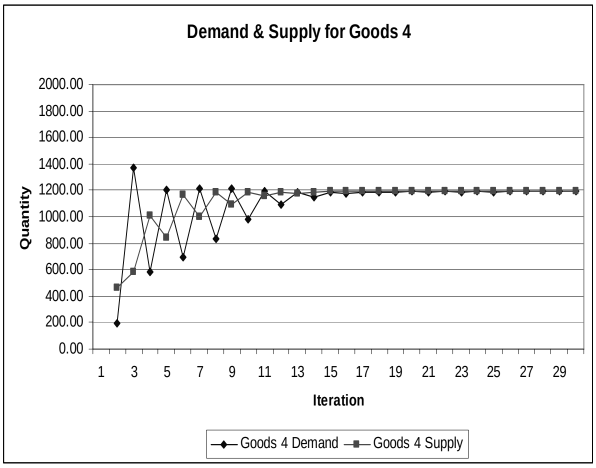

Figure 7(d): Demand and Supply Fluctuation for Goods4

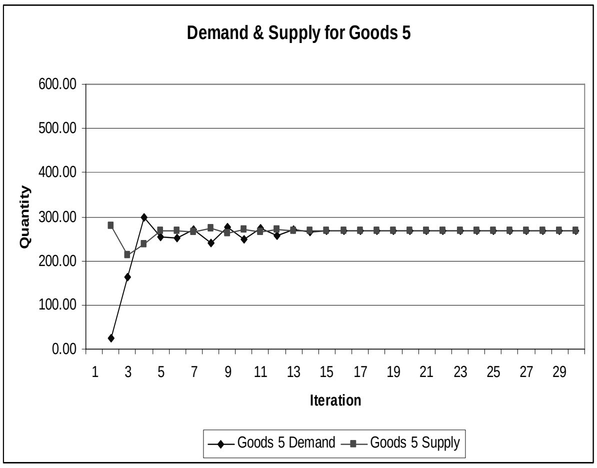

Figure 7(e): Demand and Supply Fluctuation for Goods5

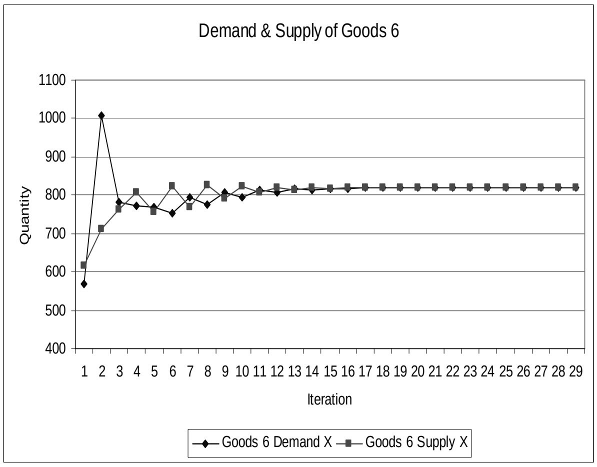

Figure 7(f): Demand and Supply Fluctuation for Goods6

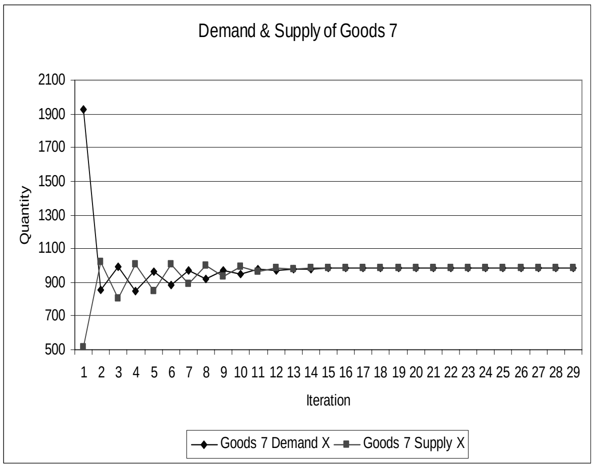

Figure 7(g): Demand and Supply Fluctuation for Goods7

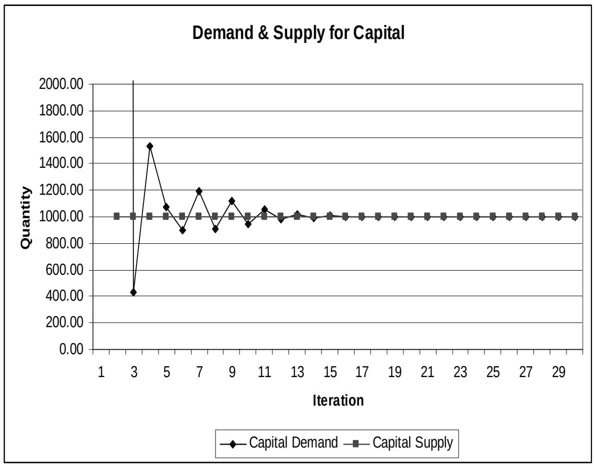

Figure 7(h): Demand and Supply Fluctuation for Capital

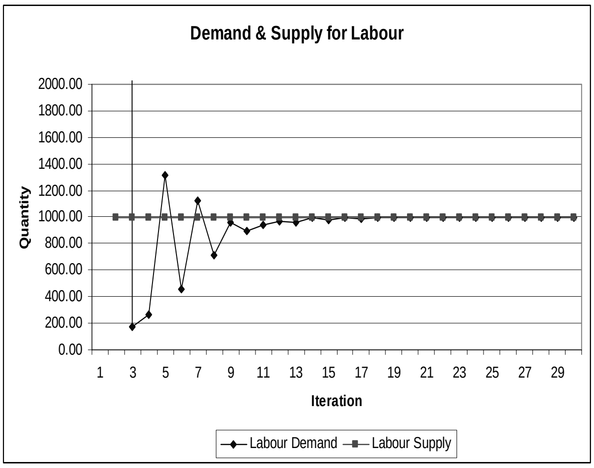

Figure 7(i): Demand and Supply Fluctuation for Labour

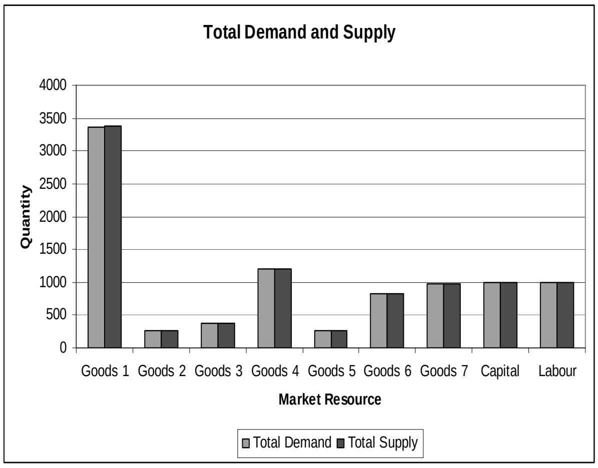

Figure 7(j): Total Demand and Supply for Market Resources

We ran a simulation on an Intel P4 (3.2GHz) machine, varying the number of traders in the market from the original number of 19 traders. Figure 8 and Table 5 show this variation.

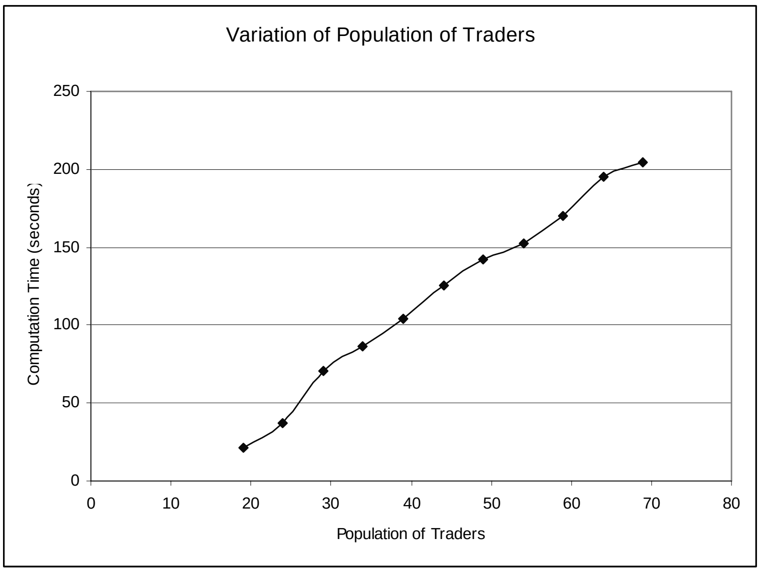

Figure 8: Variation of Population of Traders with Computational Time

Traders	19	24	29	34	39	44	49	54	59	64	69
Time (sec)	21.359	36.734	70.36	86.078	104.219	125.39	142.25	152.828	169.891	195.172	204.329

Table 5: Variation of Population of Traders with Computational Time

To confirm the correctness of the results we have obtained from our market model we compare with analytical conditions for market clearing. For market to clear, it has been proven that the Marginal Rate of Substitution (M.R.S.) as shown in equation (12) between two goods for all the market participants must be the same. We confirmed this by finding the price ratio for the two final goods (goods6 & 7) demanded only by the pure consumers and the result is represented by equation (13):

$$\frac{dg_i}{dg_j} = -\frac{\dfrac{\partial u(\mathbf{g})}{\partial g_j}}{\dfrac{\partial u(\mathbf{g})}{\partial g_i}} \tag{12}$$

Where $U(\mathbf{g})$ = utility on all market resources

$$\frac{p_6}{p_7} = \frac{\alpha_6^c}{\alpha_7^c} * \frac{g_7^c}{g_6^c} \tag{13}$$

From the price vector and resource allocation, we find the price ratio to be approximately equal for consumers 8 – 12 demand goods 6 and 7. We also confirmed the weak axiom of conservation of product in the Walrasian market to confirm our result. The total number of the final goods demanded by the pure consumers is approximately equal to that which is supplied by producer agents *m1* and *m2*. Furthermore, comparing our results with the tatonnement algorithm, we were able to confirm the correctness of the resource allocation matrix. See tables 6 and 7 below for results:

	Consumer 8	Consumer 9	Consumer 10	Consumer 11	Consumer 12
Index (α_6)	0.27	0.18	0.36	0.29	0.44
Index (α_7)	0.73	0.82	0.64	0.71	0.56
Demand (g_6)	229.3702	86.1772	190.757	135.0919	222.3829
Demand (g_7)	304.5047	192.7665	166.516	162.4005	138.9743
M.R.S	**0.491019**	**0.491019**	**0.491019**	**0.491019**	**0.491019**

Table 6: Market Clearing Marginal Rate of Substitution (MRS) for Goods *g6* and *g7*

	Demand	**Supply**
Goods6	863.7792	863.1987
Goods7	965.1621	964.2484

Table 7: Total Demand and Supply for Goods *g6* and *g7*

Performance of Algorithm

Comparing the speed of execution of our algorithm with the price tatonnement algorithm, we found our algorithm to be at least three times faster than the price tatonnement algorithm running under the same conditions. When we compared the resource allocation result with that of the price tatonnement algorithm, we got an accuracy of 1 unit of commodity while that of the price tatonnement is about 2 units of commodity. Table 8 shows the equilibrium price vector arrived at when the Walrasian price tatonnement algorithm was used. As shown in

Figure 8, we have a linear time variation with number of traders in the computational time measurement of the MOP algorithm.

Goods1	Goods2	Goods3	Goods4	Goods5	Goods6	Goods7	Capital	Labour
8.90E-03	8.81E-03	4.56E-02	6.93E-02	2.42E-02	0.149791	0.305216	0.273307	0.114921

Table 8: Equilibrium Price Vector from Walrasian Price Tatonnement Algorithm

In Figures 9(a) and 9(b) we show how equilibrium price vector is reached in a three-dimensional plot for simulation runs using the MOP algorithm and the tatonnement algorithm respectively. In these simulations, we make use of three goods in the market just for validation purposes. While the MOP algorithm shows a situation in which equilibrium point is approached in big steps (less than 30 iterations), the tatonnement shows a movement towards equilibrium in relatively smaller steps (requiring about 50,000 iterations) even though, the movement appears to be more rapid. The big jumps in the MOP algorithms accounts for its quicker arrival at the market clearing price vector.

In a previous research [3], the market-oriented programming procedure presented in this paper was compared with the Scarf algorithm in market made up of two resources and two trading agents and the MOP algorithm was found to be a lot more efficient than the Scarf algorithm based on fixed point theorem. The greater speed of the MOP algorithm can still be traced to the fact that it minimizes its search space as compared to the Scarf algorithm. The accuracy is also higher due to reasons discussed under the *searching for equilibrium* section.

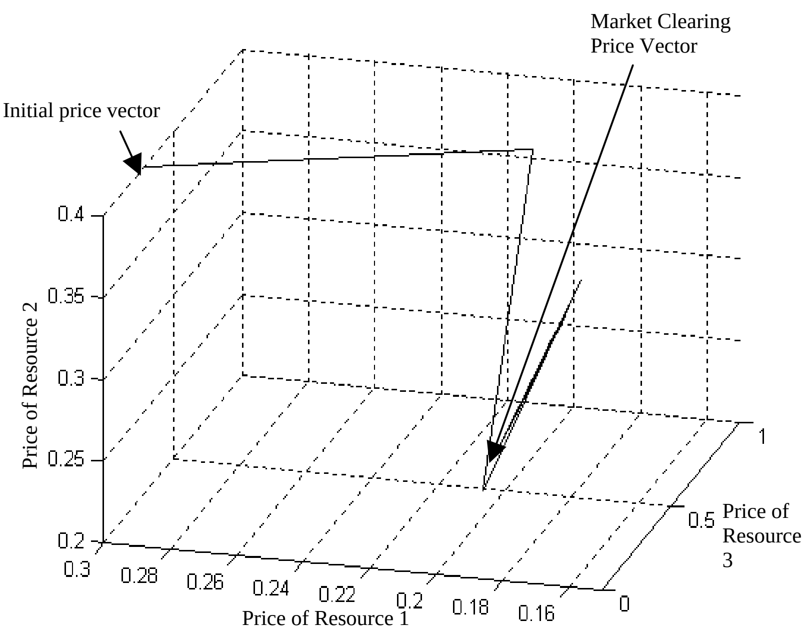

Figure 9(a): MOP Simulation with 3 goods

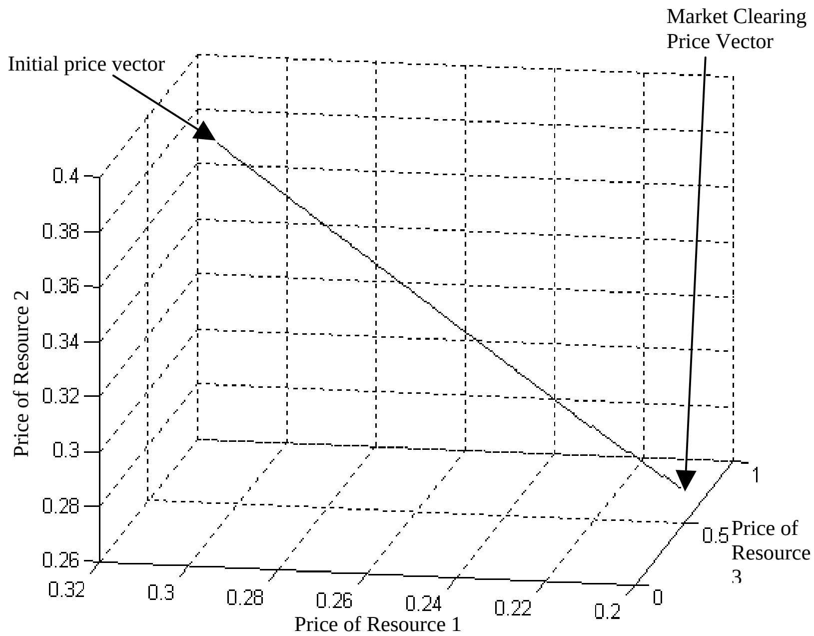

Figure 9(b): Tatonnement Algorithm Simulation with 3 goods

VARIATION OF MACROECONOMIC INDICES

In order for firms to take advantage of opportunities in different regions of the global economy, they must be able to estimate the impact economic activities in such regions will have on their facility location decisions. For instance, while it may be cost-lucrative to produce in a certain region, impediments to trades such as duties may increase distribution burden. Another area of concern is to be able to evaluate the effects the cost of primary production factors – capital and labour – will have on the supply network. In some cases, whereas the cost of labour is very low in an area compared to other production regions, infrastructural development in such an area may make location of facilities there a poor decision. Usually many of these microeconomic indices such as unemployment rate, per capita income, Gross Domestic Product (GDP) are interdependent and they vary from region to region. The competitive market model presented here is used to illustrate what effects some of these indices will have on a supply network. We use the same supply network model as depicted in figure 4.

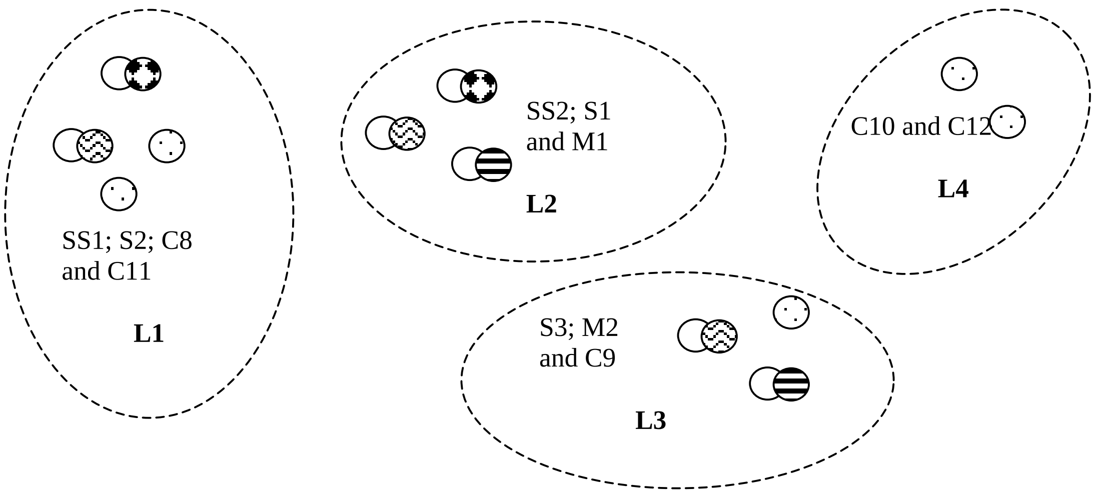

Figure 10: Global Distribution of Supply Network Units

Experiment Procedure

Step 0: *Start*
Step 1: *Initialize trading agents*
Step 2: *Set initial macroeconomic environment*
Step 3: *Execute resource-allocation algorithm*
Step 4: *Output market clearing prices of commodities, profits, demand and supply of agents*
Step 5: *Check for Changes in macroeconomic environment (locally or globally)*
Step 6: *If any change occurs go to step 3*
Step 7: *Plot variation of macroeconomic changes with selected trade parameter*
Step 8: *Terminate*

The procedure listed above briefly describes a multi-agent trading scenario in which all the trading agents not only react to price changes in the economy, but the trading environment also responds to changes in macroeconomic parameters. When any change occurs in these parameters at any location, the trading agents within these location respond accordingly by restructuring there preference indices or the market mechanism responds by changing the price on the tote board. Any of these events will cause agents to adjust there bids for market commodities which then results in execution of the resource allocation protocol. The process continues until the macroeconomic conditions in all the locations stabilize.

The simulation process was done in two phases. First, we vary the macroeconomic indicators globally and uniformly across the supply network. We then perform local variations of the macroeconomic variables assuming a network topology shown below in figure 6. The topology shows how the different units in the network are distributed into four locations L1 – L4. This is for us to illustrate the effects when the entire supply network is localized and when it is distributed. The global variation represents the entire network being localized within the same national economic boundary.

For the two indicators that are being investigated, we simulate the effects of local variations on the supply network by varying the indicators in each location while others remain constant. We present only the results for two of the four locations (locations L1 and L4).

Effect of Per capita Income Variation

We vary the per capita income by gradually reducing the endowment of pure consumers in capital and increasing their endowment for labour at the same rate. The reason for this is that the per capital income of a nation is the ratio of her gross domestic product to the population of the country. Therefore, a reduction in per capita income presupposes either an increase in the population of the country or a decrease in the gross domestic product or both. Hence, we represent a decrease in the gross domestic product by reducing the capital endowments of consumer agents and an increase in the labour endowments of the same class of agents is used to represent an increase in population.

We plot the effect of this variation on prices of the final goods and the primary factors as well as the effect it has on the profits and product demand for the final goods. While the variation method may represent a very simplistic way to illustrate the perturbations in resource distribution resulting from per capita income changes, it is also possible to use the model to reveal the effects of any other form variation method used provided such functions are dependent on any of the resources in the market.

Global Variation Effects of Per Capital Income

In Figures 11(a – c), when per capita income reduces, there is a reduction in the price of labour and a corresponding increase in the price of capital. This agrees with the trend in the world economy where regions with the lowest per capita income have the cheapest labour. Also, it can be seen that there is a gradual decrease in the prices of final goods which as shown in Figure 11(b) leads to a decrease in the profits of firms producing these commodities. Also, we would observe from Figures 11(a – c) that the responses of the two final products to the parameter variation in terms of profit and demand that is accruable to the firm are different with commodity 6 being the more responsive. Only results for the final goods are depicted in the figures below. Similar graphs can be shown for all the other market resources.

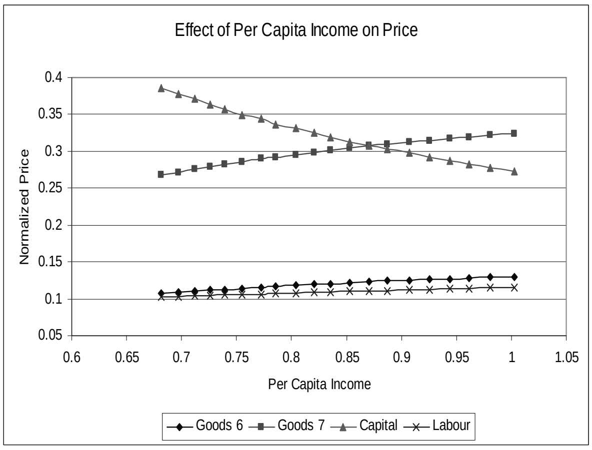

Figure 11(a): Effect of Per capita Income Variation on Price

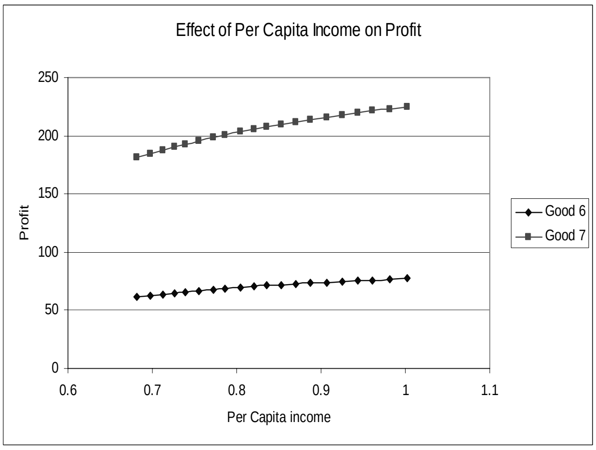

Figure 11(b): Effect of Per capita Income Variation on Profit

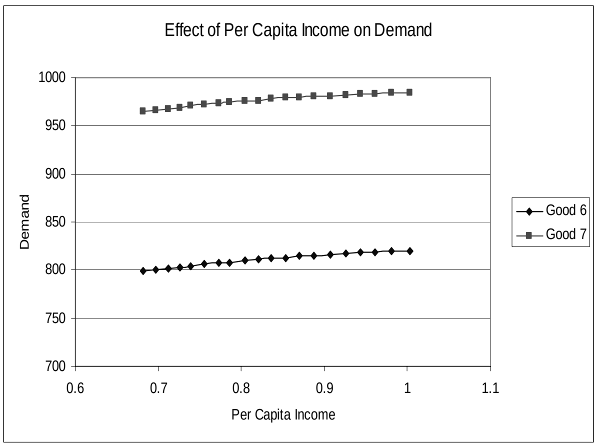

Figure 11(c): Effect of Per capita Income Variation on Demand

Local Variation Effects of Per Capital Income

First, we present results for locations L1 and L4 showing the effects on price of the final goods.

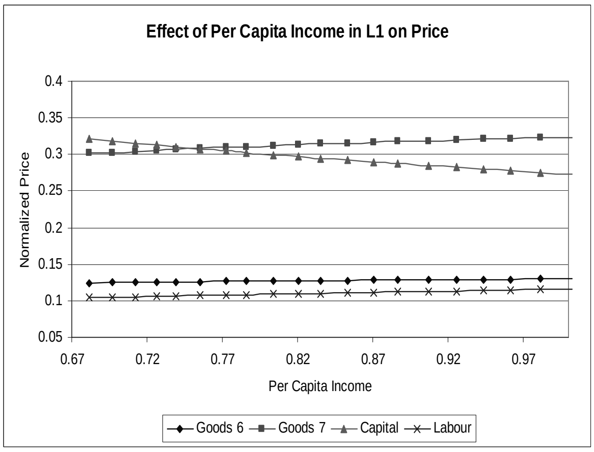

Figure 12(a): Price Effect of PCI Variation in L1

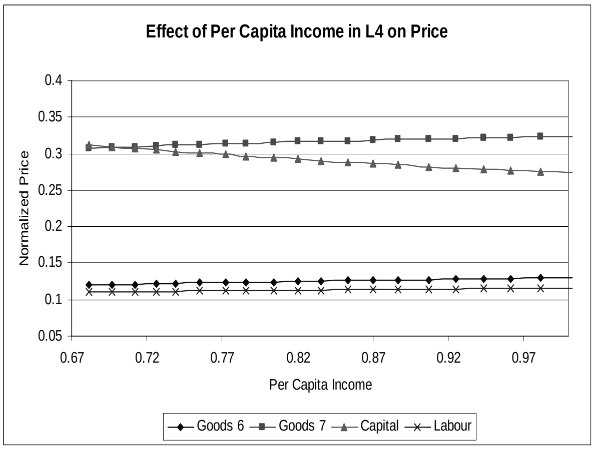

Figure 12(b): Price Effect of PCI Variation in L4

Next, we show the effects on profit generated by trading in final goods 6 and 7 for locations L1 and L4.

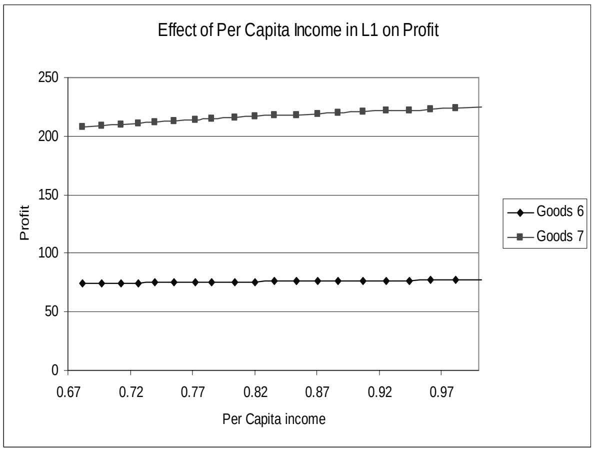

Figure 12(c): Profit Effect of PCI Variation in L1

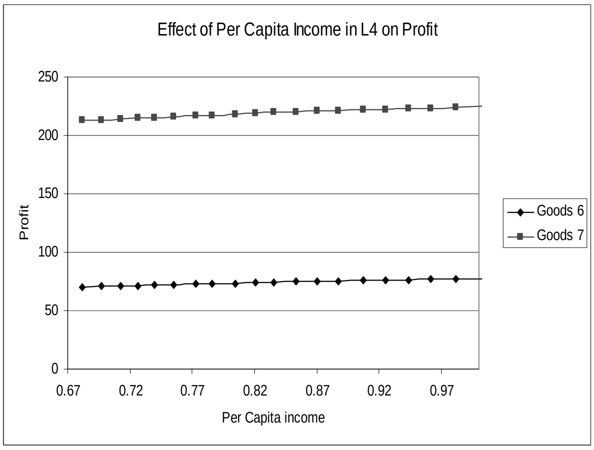

Figure 12(d): Profit Effect of PCI Variation in L4

The effects of per capita income variation in locations L1 and L 4 with respect to demand on final goods 6 and 7 are presented in figure 8(e and f)

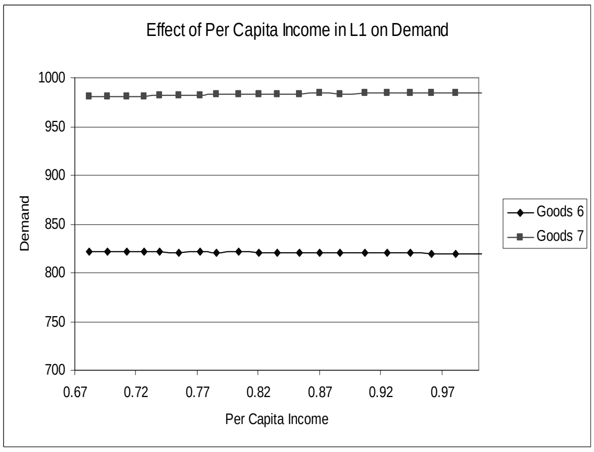

Figure 12(e): Demand Effect of PCI Variation in L1

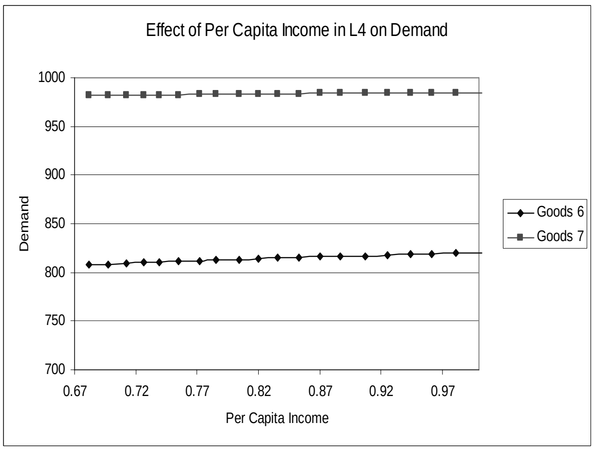

Figure 12(f): Demand Effect of PCI Variation in L4

Global Variation Effect of Interest Rate Variation

Interest rates in an economy have effects on savings and trade investment in the sense that when interest rates increase, savings is encourages and investment in other economic activities reduces. With this in mind, we vary the interest rate in the economy by gradually increasing the preference index of pure consumers for capital. We begin from an interest rate of one percent to an interest rate of twenty percent. The results are shown below:

In the interest rate simulation, we see that increase in interest rate causes a rise in the price of capital and a reduction in the prices of the final products. The price of labour remains constant since its supply remains constant in the economy. The reduction in the prices of final commodities has an effect of cutting down on profits of suppliers of these products.

As in Figures 13(b and c), it is estimated that commodity 6 will be more responsive to changes in interest rate. The rate of change of profit for commodity 6 is 0.201787 while that for commodity 7 is 0.192017. For rate of change in demand, commodity 6 has 0.02546 and commodity 7 has 0.019839. We can also perform the same computations for all the other market resources as earlier mentioned.

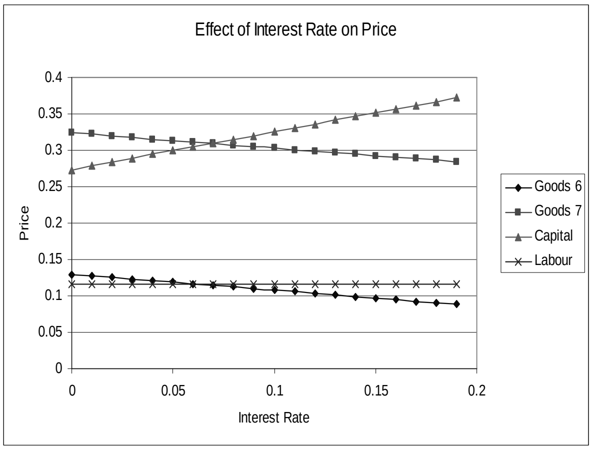

Figure 13(a): Effect of Interest Rate on Price

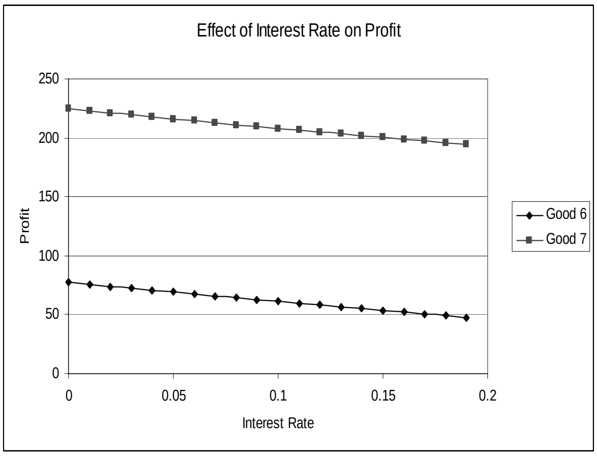

Figure 13(b): Effect of Interest Rate on Profit

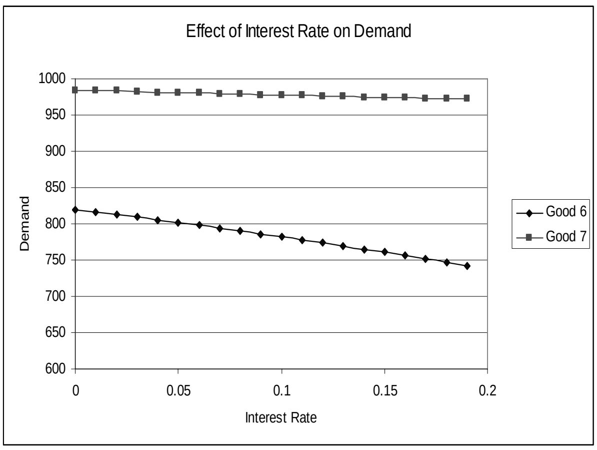

Figure 13(c): Effect of Interest Rate on Demand

Local Variation Effect of Interest Rate Variation

As in the case of per capital income variation, we show simulation results for the effects of interest rates in locations L1 and L4 on price, profit and demand of final goods 6 and 7.

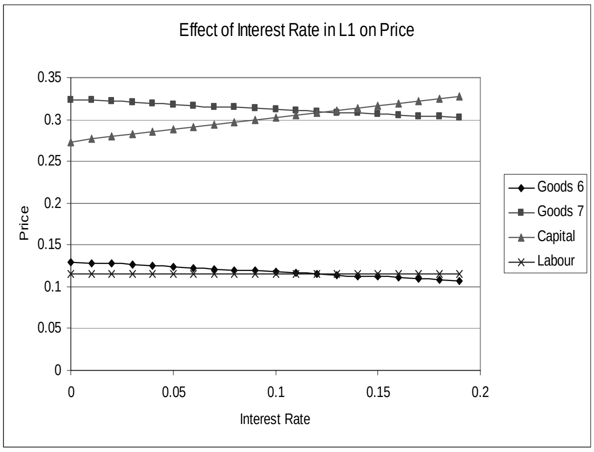

Figure 14(a): Price Effect of Interest Rate Variation in L1

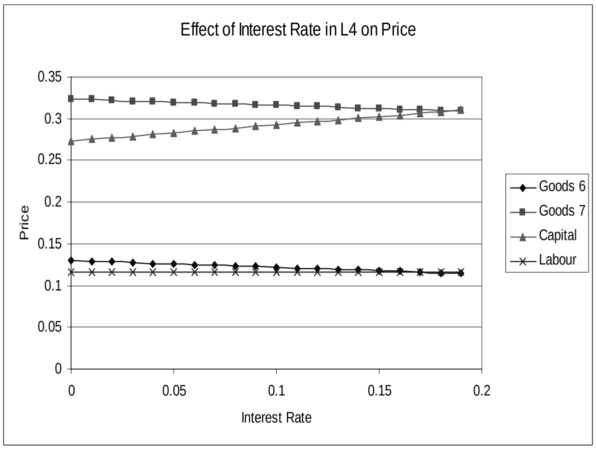

Figure 14(b): Price Effect of Interest Rate Variation in L4

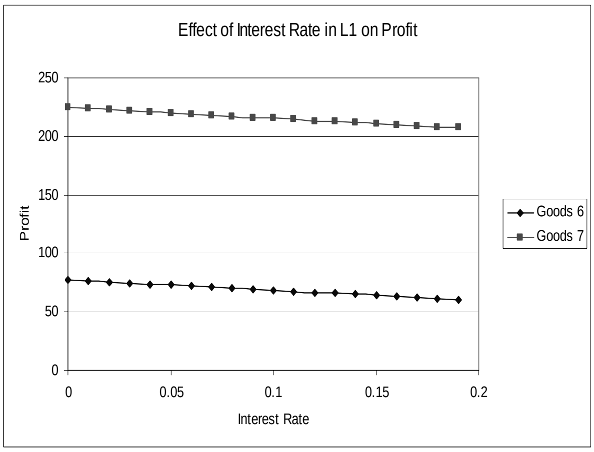

Figure 14(c): Profit Effect of Interest Rate Variation in L1

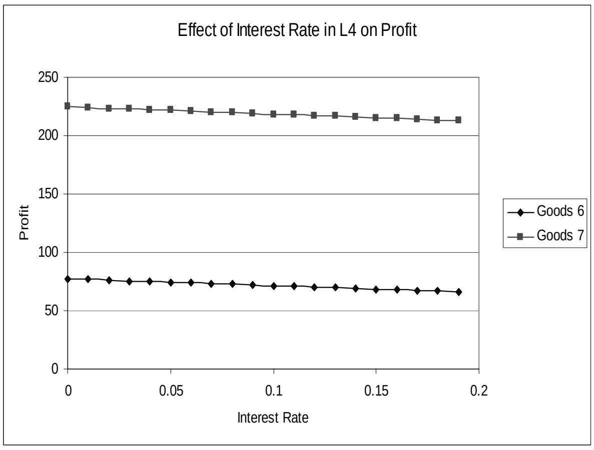

Figure 14(d): Profit Effect of Interest Rate Variation in L4

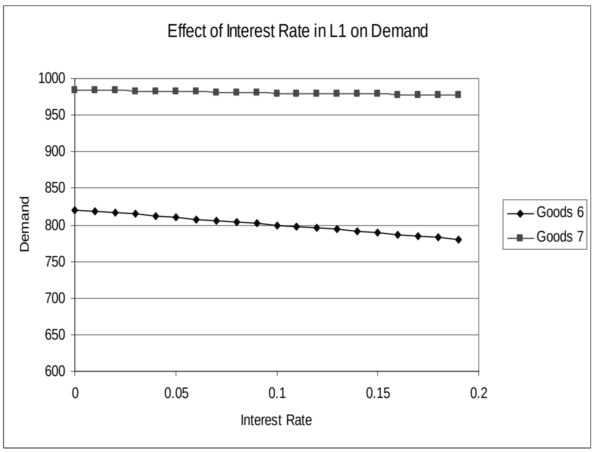

Figure 14(e): Demand Effect of Interest Rate Variation in L1

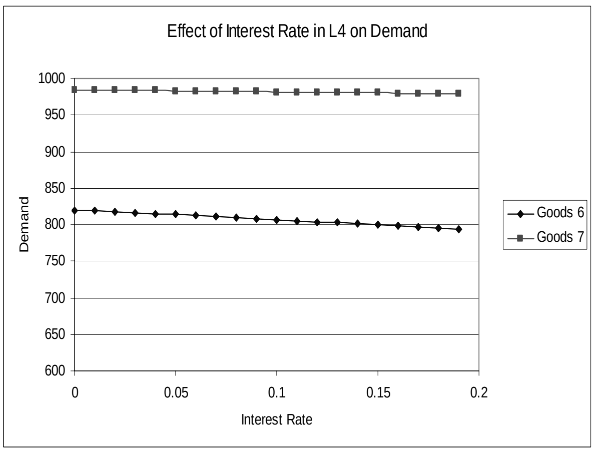

Figure 14(f): Demand Effect of Interest Rate Variation in L4

Further Discussion of Results

As can be seen from the results presented, the graph trends for the global variation and local variation of the macroeconomic variables are the same. Tables 9(a-b) gives a sample picture of how the network responds to changes in some of the locations.

Location of Variation	Price Change		Profit Change		Demand Change	
	Goods g6	Goods g7	Goods g6	Goods g7	Goods g6	Goods g7
Global	-0.023089	-0.05588	-15.60331	-43.15021	-20.87418	-19.52502
Location L1	-0.005261	-0.022304	-3.12837	-16.48281	-2.194012	-4.07616
Location L4	-0.009991	-0.015826	-7.166204	-12.02099	-12.44012	-2.785585

Table 9(a): Trading Parameter Changes (Goods 6 & 7) in Response to Per Capita Income Decrease

Location of Variation	Price Change		Profit Change		Demand Change	
	Goods g6	Goods g7	Goods g6	Goods g7	Goods g6	Goods g7
Global	-0.041757	-0.039064	-29.8029	-30.11771	-77.69082	-11.65972
Location L1	-0.022768	-0.0219	-16.60458	-17.31711	-39.61518	-7.159734
Location L4	-0.01522	-0.014732	-11.20269	-11.79196	-25.81708	-4.970778

Table 9(b): Trading Parameter Changes (Goods 6 & 7) in Response to Interest Rate Increase

Figure 12(a-b) follow the same trend as Figure 11(a) showing that, as per capita income decreases, the cost of capital increases while the cost of labour reduces. However, the rates at which these effects on the supply network occur differ with respect to the location in which the variation is experienced. For example, the price effect on capital is likely to be more on the supply network when there is a change in location L1 as against location L4, the same goes for the price effects on the final goods. The reason for this can be justified based on the level of economic activities in the two locations. While production agents in location L1 will induce demand on capital, there are no production agents in location L4; therefore there is little effect on the price of capital when there is a change in per capita income in location L4. This may also be seen as the reason for the same effect on price in the case of interest rate variation as presented in Figure 14(a-b).

With regards to the profit generated from trading in the final goods 6 and 7, a decrease in per capita income in location L1 affects final goods 7 more adversely than when there is a change in location L4. On the contrary, a decrease in per capita income in L4 is more likely to affect profits on goods 6 than when the same occurs in location L1. When the profits are aggregated however, location L4 can be said to be more tolerant to changes in per capital income when profit on the final goods are considered. When there is an interest rate increase, location L4 fares better on both goods in terms of profit generated. The result can be attributed to the fact that there are more consumers of final goods in location L4 than in L1. The total demand effects on the final goods follow the same trend as in the profit generated. In fact, the demand is responsible for the profit generated.

In summary, we have been able to show, through simulation, how changes in the macroeconomic environment of a location within a supply network can affect the entire network. Fundamentally, the level of economic activities in a region affects the price of market resources in that region but the profitability of trading in a region can only be determined through the complex relationship existing among the agents in that region. This complex interrelationship is a function of the technology of firms in the network and the preferences of consumer agents in the different regions spanning the supply network. While a normative model of such a network may be very cumbersome and may sometimes prove next to impossible, especially when there so many agents involved, the simulation procedure we have described may be a good candidate for evaluating the supply network. Also, the results we have from simulations show that the more distributed the supply network is, the more robust it becomes. A global variation of the supply network can be likened to a supply network within the same national economic boundary and results show that the effect of changes in the environment will affect the network more as compared with a partial effect in the case of a distributed supply network. This also explains why more and more firms are embracing globalization of their operations.

CONCLUSION

We have presented a competitive market-based model for optimization of resource allocation in a supply network and we used this model to show how the effects of macroeconomic indicators on a supply network can be estimated when there is a global variation and more specifically, when there are local variations just in a particular location within the network. In our model, we simplified the representation of these indicators since the goal is not to show the complex interrelationships between these macroeconomic variables. However, going by previous works that have been done in macroeconomics [8, 12, 13], some of these behaviours can be carefully incorporated into our model and their effects can be measured in terms of how the supply network responds to these perturbations.

The major contribution of this work is in employing models in neo-classical economics in deriving a framework for strategic planning of the supply network of firm given that the various agent parameters can be reasonably estimated. We have shown that the model presented is more computationally efficient than some of the previous algorithms used in computing general equilibrium for a multi-commodity market presented in this paper. The equilibrium search procedure which is based on binary search leads to greater speed in the movement towards equilibrium. In the multi-layer supply network model used, the profits generated by the producer agents are shared by the consumer agents in proportion to their investment in the economy. It is also possible to develop a framework for a biased sharing of profit among the agents. It should be mentioned however, that, while this method may be promising for approximating pareto resource distribution in a supply network, some assumptions on which the Walrasian market model is based (weak axiom of revealed preference; assumption of gross substitutionality of market resources; weak axiom of profit maximization) may serve as a major drawback for the model in situations where there are strong dependencies among the intermediate goods in the market; an area where combinatorial optimization techniques [9, 15] might prove inestimable, although much more complex and requiring more computational resources than the market model which we have presented. In cases involving combinatorial optimization, agents in the market are usually not price-taking or reactive agents but agents that are capable of proactive decision making.

This model can also find application in mass-customization manufacturing environment where the final products are a multiple variation of a particular product. We can use the model in determining the profitability of the various variants produced by a firm. Furthermore, we can adopt the competitive market model for a scenario where facilities are located in different regions with differences in the price of primary factors: The only modification being, increasing the number of primary factors from two to a multiple of two and the number of regions where facilities are located in the supply network. With this, we can obtain an optimal production capacity for each of the facilities in the supply network in terms of the relative value of primary factors at facility locations.

An extension to this research work would be in making use of results arrived at using the proposed model in forming a basis for developing a tactical level planning model which can be further integrated to the different planning problems at the operational level in order to have a vertically integrated supply network planning suite.

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ANALYSIS AND OPTIMAL PRODUCTION ALLOCATION POLICY OF MAKE-TO-ORDER MANUFACTURING SYSTEM WITH REVERSE LOGISTICS

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ABSTRACT

As the recent problem in supply chain management, we face the optimal production allocation problem of the remanufacturing production system meeting demand by a mix of both remanufactured products and new products. Then, it is becoming usual that collected used products are stored as reuse resources. In this case, the reverse logistics comes up as the flow of reuse resources. Therefore, we should consider the flow of reuse resources for optimizing the remanufacturing production system. Concretely, we have to decide the optimal production ratio of remanufactured products and new products in order to satisfy demand under the consideration of the production times and production costs for remanufactured products and new products. Then, the collected used product is usually held as inventory until a collected product is processed as the reuse part. Therefore, we have to consider the holding cost of collected used products for the optimal production policy of remanufacturing system with the reverse logistics. In this article, the remanufacturing production system which consists of the service centre which receives orders, the manufacturing plant for producing remanufactured products and new products and the warehouse for collected used products is supposed. We develop an open queueing network model for obtaining the optimal production allocation policy in the make-to-order remanufacturing production system meeting the demand by remanufactured products, new products, or a mix of both. We develop an open queueing network model for the purpose of obtaining the optimal production allocation policy in the make-to-order remanufacturing production system meeting demand by a mix of both remanufactured products and new products. Based on the developed open queueing network, the production costs for remanufactured products and new products, the penalty cost in the delay against the specified lead-time, and the holding cost of collected used products are evaluated. Then, the optimal production allocation policy for the make-to-order remanufacturing production system meeting demand by a mix of both remanufactured products and new products is investigated. Finally, we present some numerical examples and perform sensitivity analysis.

INTRODUCTION

In make-to-order manufacturing systems, there are complex flows of orders, production instructions, parts, and semi-finished products (work-in-process products) through stations such as customer service centers, manufacturing process, and warehouses and so on. In front of each station, there exist jobs waiting for processing. The make-to-order (MTO) manufacturing system can be described as the open queueing network (OQN) model which consists of nodes illustrating stations and directed segment of job flows meaning deterministic or stochastic route choice. Since quick response against an order from a customer is regarded as one of the service standards of a MTO manufacturing system, Vandaele *et al.*[1] have analyzed the production lead-time in a manufacturing system based on OQN. Sauza and Ketzenberg[2] have dealt with an optimal ordering ratio problem under the constraint of the average production lead-time. Then, Souza and Ketzenberg[2] also have defined the MTO remanufacturing production system meeting demand by a mix of both remanufactured products and new products as OQN. Under the condition that the service cost and service time property of the remanufactured product manufacturer are different from those of the new product manufacturer, the proportion of demand that is filled with the remanufactured product has been investigated under the constraint of the average production lead-time. Furthermore, Takemoto and Arizono[3][4] have investigated an economical production allocation plan to some plants under an MTO manufacturing environment with a kind of loss by the delay of due date. They[3][4] also have formulated the MTO manufacturing system with some plants using the OQN theory and evaluates the expectation and variance of the lead-time. Then, the loss by the delay of due data has been evaluated using an idea of distribution free approach which utilizes the expectation and variance, and the decision procedure about the production allocation rate has been indicated.

In a recent trend of remanufacturing by reuse, Souza and Ketzenberg[2] have considered the MTO remanufacturing production system meeting demand by a mix of both remanufactured products and new products. Then, although they have considered the disposal cost of reuse parts in the case that the yield of remanufactured products is less than the collected used products, the inventory fluctuation and inventory cost of collected used products have not been considered. Therefore, the reverse-logistics of a used product collected for the purpose of getting a reuse part has not been necessarily considered sufficiently by Souza and Ketzenberg[2]. It is usual that collected used products are held as inventory once and then processed to reuse parts in response to demand. In addition, with randomness of product life, it is ordinary that the collection of used product from the market occurs at random. Then, the inventory of collected used products fluctuates based on the relation of the rate of collection and the rate of reuse. In this article, we investigate the fluctuation of this inventory of collected used products based on the queueing theory, too. Then, in addition to processing costs of products and loss by the delay of due date of a product, we consider the holding cost of collected used products which Souza and Ketzenberg[2] have not considered. Moreover, we investigate the economical production allocation policy for new products and remanufactured products.

MODEL DESCRIPTIONS

We consider MTO manufacturing system which meets demand of products ordered from customer in sales center by manufacturing a new product with new parts and a remanufactured product with reuse parts. In the MTO manufacturing system, both remanufactured products and new products are produced at one manufacturing plant. Then, we consider the scenario where new and remanufactured products are perfect substitutes, and then demand (customer order) can be met with either a new or remanufactured product. The production instruction to the new product is brought to the manufacturing plant, and then the new product is manufactured by using the new part. In this case, we assume that the new part can be supplied in response to order of processing new product. While, it is assumed that the collected used product is held as inventory once and then the reuse part is abstracted from collected used product in response to order of remanufactured product. In addition, when the production instruction to the remanufactured product from the sale center is brought to the warehouse, the collected used product is processed to reuse the part, and then the reuse part is moved to the manufacturing plant and assembled into the remanufactured product. However, if there is no collected used product in the warehouse, the production instruction to the remanufactured product is changed to the production instruction to the new product. Then, the changed production instruction to the new product is brought to the manufacturing plant from the warehouse, and the new product is manufactured by using the new part. Remark that this fact means that the inventory information of the collected used product in the warehouse is not shared.

We show the diagram of a make-to-order manufacturing system above mentioned in **Figure 1**. In MTO manufacturing system shown in **Figure 1**, the order of the product from customer is received in the sales center at first. Then, the processing for the production instruction to either new or remanufactured products is executed in the sales center. Further, the production instruction to remanufactured product brings to the warehouse with the proportion p of demand, stochastically. Then, if there is the inventory of collected used product, the collected used product is processed to reuse the part, and then the reuse part is moved to the manufacturing plant and assembled into the remanufactured product. In contrast, when there is no collected used product in the warehouse, the production instruction to the remanufactured product is changed to the production instruction to the new product. Then, the changed production instruction to the new product is brought to the manufacturing plant from the warehouse, and the new product is manufactured by using the new part. The production instruction to the new product is directly brought to the manufacturing plant with the proportion $1-p$ of demand from the service center, and then the new product is manufactured by using the new part.

In **Figure 1**, the solid line from the warehouse to the manufacturing plant represents the flow of the reuse part with the production instruction to a remanufactured product. The dotted line in **Figure 1** represents the flow of the production instruction to a new product changed in the case that there is no collected used product in the warehouse. Thereafter, the new product and the remanufactured product are delivered to a customer without distinction. In this way, the used product collected from customer is held once as inventory in the warehouse. And then, the collected used product is to wait for the production instruction to the remanufactured product, that is, this flow of the used product collected from customer means the reverse logistics against the flow until the delivery of the product from customer order.

We define that the sales center, inventory function in the warehouse, processing function for taking out the reuse part from a collected used product, function of issuing again the production instruction to a new product from the warehouse to the manufacturing plant, and the manufacturing plant are represented as stations 0, 1, 2, 3 and 4, respectively. In addition, $j=1$ denotes the new product, and $j=2$ denotes the remanufactured product. In the station 0 (service center), we can consider the customer order as the input, the issue of

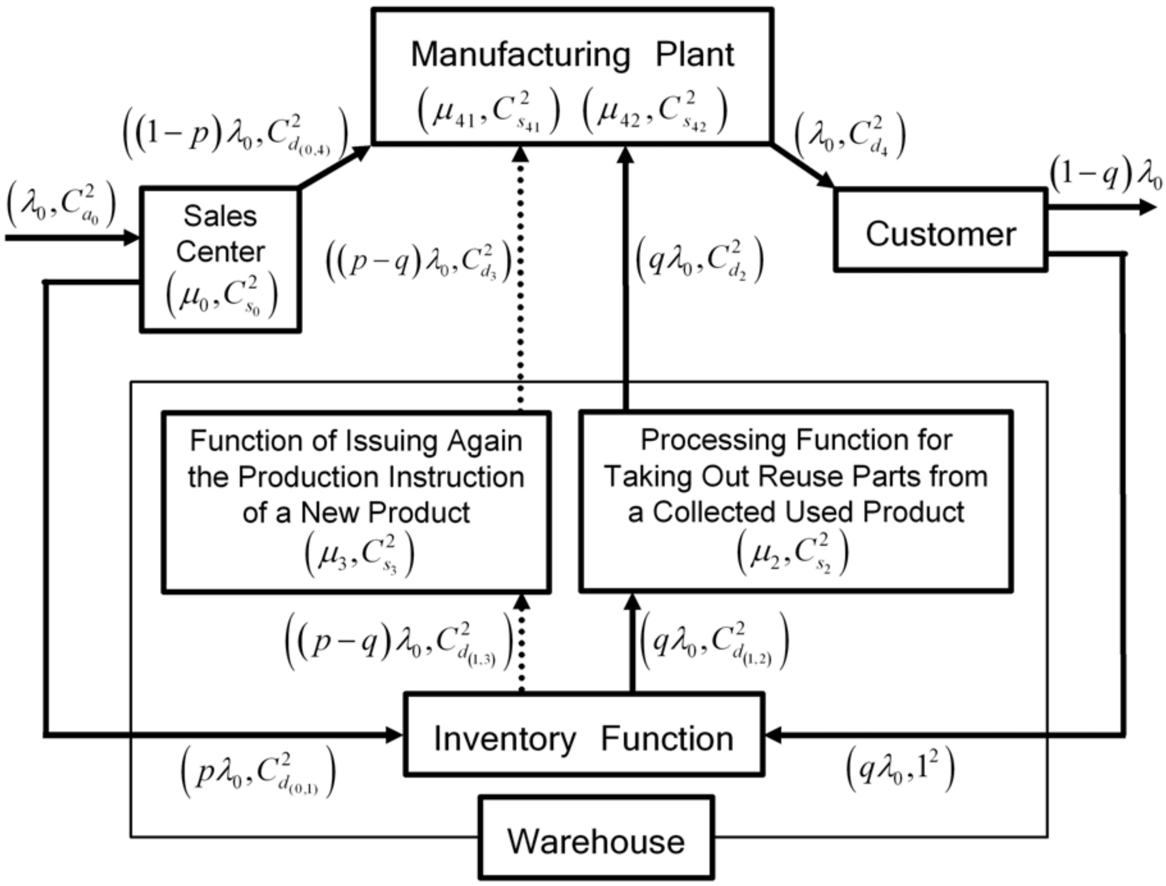

Figure 1 Diagram of make-to-order manufacturing system with reverse logistics

the production instruction at the service center as the processing, and the production instruction as the output from the service center. In the same way, the input, processing and output at each station can be defined. However, we have to pay the attention in the definition of the input and processing at the station 1 (inventory function). Because of the existence of the reverse logistics at the station 1, the input at the station 1 should be defined as the collection of used product, the processing should be defined as the arrival of the production instruction to remanufactured product. Then, each station can be regarded as GI/G/1 queueing model. Further, the MTO manufacturing system in **Figure 1** is interpreted as the open queuing network. We introduce the following notations used in analysis of this study:

- λ_i : input rate at the station $i\,(=0,1,2,3,4)$, that is, mean time between arrivals of input = $1/\lambda_i$.
- λ_{4j} : input rate in production instruction to the product $j\,(=1,2)$ at the station 4.
- $C^2_{a_i}$: squared coefficient of variation (scv) of input inter-arrival time distribution at the station $i\,(=0,1,2,3,4)$.
- μ_i : processing rate at the station i $(=0,1,2,3,4)$, that is, mean processing time = $1/\mu_i$.
- μ_{4j} : processing rate of the product $j\,(=1,2)$ at the station 4.

$C_{s_i}^2$: scv of processing time distribution at the station $i\ (=0,1,2,3,4)$.

$C_{s_{4j}}^2$: scv of processing time distribution of the product $j\ (=1,2)$ at the station 4.

$\nu_{(m,n)}$: output rate from the station $m\ (=0,1,2,3)$ to the station $n\ (=1,2,3,4)$.

ν_i : output rate from the station $i\ (=0,1,2,3,4)$.

$C_{d_{(m,n)}}^2$: scv of output inter-departure time distribution from the station $m\ (=0,1,2,3)$ to the station $n\ (=1,2,3,4)$.

$C_{d_i}^2$: scv of output inter-departure time distribution from the station $i\ (=0,1,2,3,4)$.

ρ_i : traffic density $\rho_i = \lambda_i / \mu_i$ at the station $i\ (i=1,2)$.

c_i : processing cost per unit product at the station $i\ (i=0,2,3)$.

c_{4_j} : processing cost per unit product at the station 4

c_h : holding cost per unit used product pre unit time at the station 1.

ℓ : loss by the delay of due date per unit product per unit time.

T : prescribed lead time (due date),

p : proportion of production instruction to remanufactured product (decision parameter).

q : rate of collection of used products (known).

Then, suppose that λ_0, $\mu_i\ (i=0,2,3)$, $C_{a_i}^2\ (i=0,1)$, $\mu_{4j}\ (j=1,2)$, $C_{s_i}^2\ (i=0,2,3)$, and $C_{s4_j}^2\ (j=1,2)$ are given. Since the collection of used product occurs at random, the collection inter-arrival time follows exponential distribution. Therefore, the scv $C_{a_1}^2$ of collection inter-arrival time is 1. In addition, since the rate of collection of used product from market is known as q, the collection inter-arrival time of collected used products follows the exponential distribution with collection rate $q\lambda$.

In this research, we analyze the system properties, e.g. the production lead time from acceptance of the order to shipment and so on, for the purpose of evaluating the optimal production instruction proportion p for the remanufactured product. Then, we consider following cost elements.

1. processing costs at the sales center, manufacturing plant, and warehouse
2. loss by the delay of due date
3. holding cost of collected used products in the warehouse

CHARACTERISTICS OF TIME DISTRIBUTION AT EACH STATION

As previously mentioned, each station is regarded as GI/G/1 queueing model. We consider the property of the queueing model at each station as follows.

The traffic density ρ_i at station i is generally denoted as $\rho_i = \mu_i / \lambda_i$. The output rate ν_i and scv $C_{d_i}^2$ at the station i is given based on the input rates and scv of input inter-arrival time distribution, and the processing rate and scv of processing time distribution as fallows:

$$\nu_i = \lambda_i , \tag{1}$$

$$C_{d_i}^2 = \rho_i^2 C_{s_i}^2 + \left(1-\rho_i^2\right) C_{a_i}^2 , \tag{2}$$

where, because the production instruction from the station 0 is conveyed to the station 1 and 4 respectively as output, it is necessary to evaluate these separately. Provided that the production instruction to a remanufactured product is conveyed to the station 1 at the proportion p, the output rate $\nu_{(0,1)}$, $\nu_{(0,4)}$ and scv $C_{d_{(0,1)}}^2$, $C_{d_{(0,4)}}^2$ from the station 0 to the station 1 or 4 are derived by using the proportion p based on the following expressions:

$$\nu_{(0,1)} = p\lambda_0 , \tag{3}$$

$$\nu_{(0,4)} = \left(1-p\right)\lambda_0 , \tag{4}$$

$$C_{d_{(0,1)}}^2 = pC_{d_0}^2 + \left(1-p\right) , \tag{5}$$

$$C_{d_{(0,4)}}^2 = \left(1-p\right)C_{d_0}^2 + p . \tag{6}$$

We consider the property of the station 1 next. At the station 1, we pay attention to the reverse logistics of collecting the used product. Concretely, at the station 1, the arrival of the collected used product is interpreted as the input. The collected used product of the inventory (i.e., queue) in the warehouse is processed to the reuse part by the production instruction from the station 0, and then, the processed reuse part is moved to the station 2. Therefore, it is natural to regard the arrival of the production instruction as the processing of the collected used product. The input rate λ_1 and scv $C_{a_1}^2$ of the input inter-arrival distribution at the station 1 is given as follows:

$$\lambda_1 = q\lambda_0 , \tag{7}$$

$$C_{a_1}^2 = 1 . \tag{8}$$

On the other hand, the processing rate μ_1 and scv $C_{s_1}^2$ of the processing time distribution are explained as the following expressions based on the property of the output from the station 0 to the station 1:

$$\mu_1 = \nu_{(0,1)} = p\lambda_0 \tag{9}$$

$$C_{s_1}^2 = C_{d_{(0,1)}}^2 = pC_{d_0}^2 + \left(1-p\right) \tag{10}$$

Here, the output of the collected used product from the station 1 to the station 2 can be interpreted as the input to the station 2. Therefore, the input rate λ_2 and scv $C_{a_2}^2$ at the station 2 can be given by using the expressions (1) and (2) as follows:

$$\lambda_2 = \nu_{(1,2)} = q\lambda_0 , \tag{11}$$

$$C_{a_2}^2 = C_{d_{(1,2)}}^2 = \left(\frac{q}{p}\right)^2 C_{s_1}^2 + \left\{1-\left(\frac{q}{p}\right)^2\right\} . \tag{12}$$

On the other hand, if the station 1 has no inventory, the production instruction to the new product is given afresh from the station 1 via the station 3 (the reissuing function of production instruction to new products with new part). We define the following approximate analysis on this flow. The probability that there is no collected used product inventory in the station 1 is given as $\left(1-\rho_i\right)$. The input to the station 3 occurs when there is no collected used product in the station 1 and the production instruction from the station 0 to the station 1 is given. Therefore, the input rate λ_3 at the station 3 is given as follows:

$$\lambda_3 = \nu_{(1,3)} = p\lambda_0\left(1-\rho_i\right) = \left(p-q\right)\lambda_0 . \tag{13}$$

Further, we consider the scv of input inter-arrival time distribution at the station 3. Since the input to the station 3 happens by the production instruction to remanufactured product in the case that there is no collected used product in the station 1, the interval of the input to station 3 is equivalent to the time that the collected used product inventory exists in the station 1. Therefore, we consider the busy period for the M/G/1 queueing model with the input rate $\lambda_1 = q\lambda_0$, output rate $\mu_1 = p\lambda_0$ and scv $C_{s_1}^2$.

Suppose the M/G/1 queueing model with the input rate λ, output rate μ and scv C_s^2, and describe $S(t)$ as the service time distribution and $B(t)$ as the busy period distribution. Furether, we define the Laplace transforms of $S(t)$ and $B(t)$ as $S^*\left(\theta\right)$ and $B^*\left(\theta\right)$, respectively. Then, we have the following relation:

$$B^*\left(\theta\right) = S^*\left(\lambda+\theta-\lambda B^*\left(\theta\right)\right).$$

Through $B^*\left(\theta\right)$ is differentiated with θ, we have

$$B^{*\prime}\left(\theta\right) = S^{*\prime}\left(\lambda+\theta-\lambda B^*\left(\theta\right)\right)\left(1-\lambda B^{*\prime}\left(\theta\right)\right),$$

$$B^{*\prime\prime}\left(\theta\right) = S^{*\prime\prime}\left(\lambda+\theta-\lambda B^*\left(\theta\right)\right)\left(1-\lambda B^{*\prime}\left(\theta\right)\right)^2 + S^{*\prime}\left(\lambda+\theta-\lambda B^*\left(\theta\right)\right)\left(-\lambda B^{*\prime\prime}\left(\theta\right)\right).$$

Further, by substituting the following relation into the above equations

$$B^*\left(0\right) = \int_0^\infty dB\left(t\right) = 1,$$

$$S^{*\prime}\left(0\right) = -\int_0^\infty t dS\left(t\right) = -\frac{1}{\mu},$$

$$S^{*\prime\prime}\left(0\right) = \int_0^\infty t^2 dS\left(t\right) = \frac{C_s^2}{\mu^2} + \frac{1}{\mu^2},$$

we obtain

$$B^{*\prime}\left(0\right) = -\frac{1}{\mu-\lambda},$$

$$B^{*\prime\prime}\left(0\right) = \frac{\mu\left(C_s^2+1\right)}{\left(\mu-\lambda\right)^3}.$$

Therefore, the expectation $E_b\left[t\right]$ and the scv $C_b^2\left[t\right]$ of the busy period in the M/G/1 queueing model are derived as

$$E_b\left[t\right] = -B^{*\prime}\left(0\right) = \frac{1}{\mu-\lambda},$$

$$C_b^2\left[t\right] = \frac{B^{*\prime\prime}\left(0\right) - \left\{B^{*\prime}\left(0\right)\right\}^2}{\left\{B^{*\prime}\left(0\right)\right\}^2} = \frac{C_s^2\mu+\lambda}{\mu-\lambda}.$$

In the result, the input rate λ_3 at the station 3 based on the equation of $E_b\left[t\right]$ is obtained as

$$\lambda_3 = \left(p-q\right)\lambda_0 ,$$

and then is equivalent to equation (13). Then, we can evaluate the scv $C_{a_3}^2$ as follows:

$$C_{a_3}^2 = C_{d_{(1,3)}}^2 = \frac{C_{s_1}^2 p + q}{p-q} . \tag{14}$$

Therefore, we can derive ν_2, $C_{d_2}^2$, ν_3, and $C_{d_3}^2$ of output inter-departure time by using equations (1) and (2). By the reference, it is obvious that the reciprocal of $E\left[y\right]$ presented above is correspondent to λ_3 in equation (13).

The order rate $\lambda_{4j}\ \left(j=1,2\right)$ of the new product or remanufactured product in the station 4 is given as follows:

$$\lambda_{41} = \nu_{(0,4)} + \nu_3 = \left(1-q\right)\lambda_0 ,$$

$$\lambda_{42} = \nu_2 = q\lambda_0 ,$$

Therefore, the order rate of all products in the station 4 is

$$\lambda_4 = \nu_{(0,4)} + \nu_2 + \nu_3 = \left(1-p\right)\lambda_0 + q\lambda_0 + \left(p-q\right)\lambda_0 = \lambda_0 . \tag{15}$$

In addition, the scv $C_{a_4}^2$ of the order input inter-arrival time distribution in the station 4 is derived as

$$C_{a_4}^2 = \left(1-p\right)C_{d_{(0,4)}}^2 + qC_{d_2}^2 + \left(p-q\right)C_{d_3}^2 . \tag{16}$$

Furthermore, the service rate μ_4 and scv $C_{s_4}^2$ of the service time distribution is derived as

$$\frac{1}{\mu_4} = \sum_{j=1}^{2} P_{4j}\frac{1}{\mu_{4j}} , \tag{17}$$

$$C_{s_4}^2 = \frac{\sum_{j=1}^{2} P_{4j}\left(\frac{1}{\mu_{4j}}\right)^2 - \left(\sum_{j=1}^{2} P_{4j}\frac{1}{\mu_{4j}}\right)^2}{\left(\sum_{j=1}^{2} P_{4j}\frac{1}{\mu_{4j}}\right)^2} + \sum_{j=1}^{2} P_{4j}C_{s_{4j}}^2 , \tag{18}$$

where P_{4j} represents a ratio of the product j at the manufacturing plant, and $P_{4j} = \lambda_{4j} / \lambda_4$.

EVALUATION OF LEAD-TIME CHARACTERISTICS

By using the input rate, scv of the input inter-arrival time distribution, processing rate, and scv of the processing time distribution, the expectation $E\left[w_i\right]$ and variance $V\left[w_i\right]$ of the waiting time w_i for processing of a job in the station i is evaluated as

$$E\left[w_i\right] = \frac{\rho_i\left(C_{a_i}^2 + C_{s_i}^2\right)}{2\mu_i\left(1-\rho_i\right)}\Phi , \tag{19}$$

$$V\left[w_i\right]=\left(E\left[w_i\right]\right)^2\left(\frac{\Delta_i+1}{\Theta_i}-1\right), \tag{20}$$

where

$$\Phi_i=\begin{cases}\exp\left\{-\dfrac{2\left(1-\rho_i\right)\left(1-C_{a_i}^2\right)}{3\rho_i\left(C_{a_i}^2+C_{s_i}^2\right)}\right\} & \left(C_{a_i}^2\le 1\right),\\ 1 & \left(C_{a_i}^2>1\right),\end{cases}$$

$$\Delta_i=\begin{cases}2\rho_i-1+\dfrac{4\left(1-\rho_i\right)\left(2C_{s_i}^2+1\right)}{3\left(C_{s_i}^2+1\right)} & \left(C_{a_i}^2\le 1\right),\\ 2\rho_i-1+\dfrac{4C_{s_i}^2\left(1-\rho_i\right)}{C_{s_i}^2+1} & \left(C_{a_i}^2>1\right),\end{cases}$$

$$\Theta_i=\begin{cases}\rho_i+\dfrac{\rho_i\left(1-\rho_i\right)\left(C_{a_i}^2-1\right)\left(1+C_{a_i}^2+\rho_iC_{s_i}^2\right)}{1+\rho_i\left(C_{s_i}^2+1\right)+\rho_i^2\left(4C_{a_i}^2+C_{s_i}^2\right)} & \left(C_{a_i}^2\le 1\right),\\ \rho_i+\dfrac{4\rho_i^2\left(1-\rho_i\right)\left(C_{a_i}^2-1\right)}{C_{a_i}^2+\rho_i^2\left(4C_{a_i}^2+C_{s_i}^2\right)} & \left(C_{a_i}^2>1\right).\end{cases}$$

Furthermore, based on the expectation $E\left[w_i\right]$ and variance $V\left[w_i\right]$ of the waiting time for processing of a job, the expectation $E\left[t_i\right]$ and variance $V\left[t_i\right]$ of the residence time t_i of a job at the station i is provided as

$$E\left[t_i\right]=E\left[w_i\right]+\frac{1}{\mu_i}, \tag{21}$$

$$V\left[t_i\right]=V\left[w_i\right]+\frac{C_{s_i}^2}{\mu_i^2}. \tag{22}$$

Therefore, the expectation $E\left[t\right]$ and variance $V\left[t\right]$ of the production lead-time t from receiving an order to shipment in this MTO manufacturing system is evaluated as

$$E\left[t\right]=E\left[t_0\right]+\frac{\lambda_2}{\lambda_0}E\left[t_2\right]+\frac{\lambda_3}{\lambda_0}E\left[t_3\right]+E\left[t_4\right] \tag{23}$$

$$V\left[t\right]=V\left[t_0\right]+\frac{\lambda_2}{\lambda_0}V\left[t_2\right]+\frac{\lambda_3}{\lambda_0}V\left[t_3\right]+V\left[t_4\right]+\frac{\lambda_2}{\lambda_0}\frac{\lambda_3}{\lambda_0}\left(E\left[t_2\right]-E\left[t_3\right]\right)^2 \tag{24}$$

The residence time of the collected used product in the warehouse of the station 1 is the time from the arrival at the warehouse of the collected used product to the departure to the station 2 of the collected used product. The residence time of the collected used product in the warehouse is in different time elapse from the time elapse from order to shipment. Therefore, the residence time of the collected used product in the warehouse is independent on the production lead-time, and then the residence time can be used to evaluate the holding cost in the warehouse.

DETERMINATION OF THE OPTIMAL ORDER POLICY

The production allocation policy for new product and remanufactured product is determined by optimizing under the evaluation function which consists of the processing cost at the sales center, manufacturing plant and warehouse, loss by the delay of due date, and holding cost in the warehouse. The objective function $C(p)$ is provided as the cost function pre unit time as follows:

$$C(p) = \lambda_0 c_0 + q\lambda_0 c_2 + (p-q)\lambda_0 c_3 + (1-q)\lambda_0 c_{41} + q\lambda_0 c_{42} + c_h L + \lambda_0 \ell E[t-T]^+, \qquad (25)$$

where L represents the expected inventory per unit time which is derived as

$$L = \lambda_1 E[t_1] = q\lambda_0 E[t_1],$$

by using the expected residence time $E[t_1]$ in the station 1 based on the equation (19) and (20).

$E[t-T]^+$ represents the expected delay time for the due date. When the lead-time distribution is known, $E[t-T]^+$ may be estimated exactly. Though the expectation and variance of the production lead-time can be estimated approximately in this research, it is not easy to know the production lead-time distribution exactly. Therefore, to make a decision only based on the limited information such as the expectation and variance of the production lead-time which is derived in this research, we adopt the Distribution Free Approach using the inequality of Cauchy-Schwarz.

At first, $E[t-T]^+$ is expressed as

$$E[t-T]^+ = \frac{|t-T| + (t-T)}{2}.$$

In addition, by using the inequality of Cauchy-Schwarz, $E[|t-T|]$ can be derived as follows:

$$E[|t-T|] \le \left\{E\left[(t-T)^2\right]\right\}^{1/2} = \left\{V[t] + (E[t]-T)^2\right\}^{1/2}.$$

Furthermore, we have

$$E[t-T] = E[t] - T.$$

Therefore, we can get the relation:

$$E[t-T]^+ \le \frac{1}{2}\left\{V[t] + (E[t]-T)^2\right\}^{1/2} + \frac{1}{2}(E[t]-T).$$

From the above mentioned approach, instead of the evaluated function in equation (25) which it is difficult to evaluate accurately, the substitute evaluation function $TC(p)$ is provided afresh as

$$\begin{aligned} TC(p) &= \lambda_0 c_0 + q\lambda_0 c_2 + (p-q)\lambda_0 c_3 + (1-q)\lambda_0 c_{41} + q\lambda_0 c_{42} + c_h q\lambda_0 E[t_1] \\ &\quad + \frac{\ell}{2}\lambda_0 \left\{V[t] + (E[t]-T)^2\right\}^{1/2} + \frac{\ell}{2}\lambda_0 (E[t]-T) \\ &= C_S + C_H + C_D \le C(p), \end{aligned} \qquad (26)$$

where C_S represents the processing cost per unit time substitute for the former five terms, C_H represents the holding cost pre unit time substitute for the term $c_h q\lambda_0 E[t_1]$, and C_D represents the loss by the delay of due date per unit time per unit product substitute for the latter two terms.

Though we consider the holding cost for collected used products in the evaluation functions (25) and (26), we do not consider the holding cost for reuse parts and new parts. If we need to cope with the residence cost of these products, we can be evaluated as $E[t_4]$ based on the equation (23).

NUMERICAL EXAMPLES

We derive the optimal solution by using evaluated function $TC(p)$ under some set values. At first, we give information on orders from customers as follows:

$$\lambda_0 = 1.5, \qquad C_{a_0}^2 = 0.7,$$

the information on the collection from the market as

$$q = 0.2, \qquad C_{a_1}^2 = 1.0,$$

and the information on processing time in each station as

$$\mu_0 = 5.0, \qquad C_{s_0}^2 = 0.8,$$

$$\mu_2 = 3.33, \qquad C_{s_2}^2 = 1.0,$$

$$\mu_3 = 6.66, \qquad C_{s_3}^2 = 1.5,$$

$$\mu_{41} = 2.0, \qquad C_{s_{41}}^2 = 0.8,$$

$$\mu_{42} = 3.0, \qquad C_{s_{42}}^2 = 0.9.$$

Furthermore, we give the information on each cost as

$$c_0 = 0.3, \qquad c_2 = 0.5, \qquad c_3 = 0.2, \qquad c_{41} = 3.6, \qquad c_{42} = 3.0,$$

$$c_h = 0.01, \qquad \ell = 2.0, \qquad T = 4.0.$$

And then, we examined the behavior of the evaluated function $TC(p)$ for various p. We show **Table 1** as an example of behavior of the evaluated function $TC(p)$. In **Table 1**, we observe that the evaluated function $TC(p)$ takes the minimum value for $p = 0.24$ and this value of p gives the optimal production allocation policy.

Next, **Table 2** shows the behavior of p and $TC(p)$ for the holding cost. In **Table 2**, we know that the policy increasing the value of p is adopted, because it is the best plan to minimize the residence time of the collected used product in the warehouse as the holding cost increases.

Table 1 Behavior of $TC(p)$ for p

p	$TC(p)$	C_S	$E[t]$	$V[t]$	C_D	$E[t_1]$	C_H
0.21	6.780	5.823	1.905	2.392	0.764	64.727	0.194
0.23	6.674	5.829	1.922	2.431	0.780	21.576	0.065
0.24	6.669	5.832	1.931	2.451	0.788	16.182	0.049
0.25	6.671	5.835	1.935	2.471	0.797	12.945	0.039
0.30	6.709	5.850	1.982	2.573	0.840	6.473	0.019
0.40	6.821	5.880	2.067	2.785	0.931	3.236	0.010
0.50	6.947	5.910	2.153	3.009	1.030	21.58	0.006

Table 2 Behavior of p and $TC(p)$ for c_h

c_h	p	$TC(p)$
0.01	0.24	6.669
0.05	0.29	6.786
0.10	0.33	6.875
0.20	0.38	7.001
0.50	0.47	7.260
1.00	0.57	7.560

Table 3 Behavior of p and $TC(p)$ for λ_0

λ_0	p	$TC(p)$
0.10	0.50	0.405
0.20	0.41	0.803
0.30	0.37	1.201
0.50	0.33	2.000
1.00	0.28	4.057
1.50	0.24	6.669
2.00	0.21	30.869

Last, we examine how the optimal production allocation policy changes when the order rate at the sales center varies. The result is given in **Table 3**. In **Table 3**, the decreasing of p against the increasing of λ_0 indicates that the decreasing of the production lead-time has the priority.

CONCLUSION

In this study, we have considered the optimal production allocation policy in the MTO manufacturing system in which the new product with a new part and remanufactured product with a reuse part are manufactured as perfect substitute for each other. Concretely, we have supposed that the new product and remanufactured product are mixed, and the processing cost of each station, the mean and variance of order inter-arrival time and processing time are given. In this situation, we have evaluated the loss by the delay of due date based on not only the expectation of the production lead-time but also the lead-time variance which Souza and Ketzenberg[2] did not consider. And then, we have defined the evaluation function which consists of the processing costs, loss by the delay of due date, and holding cost which Souza and Ketzenberg[2] did not consider. Based on the evaluation function, we have considered the economical production allocation plan.

In this paper, we assume that inventory information of collected used products in the warehouse does not share in the MTO manufacturing system. As Shimomura[5] points out, sharing inventory information thoroughly is not realized actually. However, if the inventory information of collected used products in the warehouse is shared thoroughly, we may bring out the production instruction efficiently in response to the presence of the collected used product in the warehouse. In the future, we would like to have the interesting research subject such as the production allocation policy when inventory information shares.

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TRACEABILITY SYSTEM FOR PROCESSED FOOD SUPPLY CHAIN WITH COMPOSITE PRODUCTION PROCESS

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ABSTRACT

This paper concerns with a traceability system for processed food supply chain. Information system which generates production and distribution history of certain product is called traceability system. Traceability information on food industry especially obtains much attention from consumers. Some traceability systems are proposed and used for fresh foods such as fresh meat or vegetables. However there are few systems for processed foods. It is difficult to trace which meat is used in which product because manufacturing process causes constantly changes of style and management unit. Furthermore, management of processed food industry is more natively difficult than that of other industry as it has composite production process. In this paper, we propose a traceability system cooperating with ERP systems and an additional order acceptance functioning with Implosion MRP scheme. We also developed a prototype system of the proposed traceability system. The prototype system is tested with the actual processed seafood company data.

INTRODUCTION

Nowadays, mass customization is widely introduced and therefore each company has to pay much attention to their products compared with mass production era. An information system which determines a target product, its production and distribution process is called a traceability system. With the system, manufacturers can guarantee their product quality and find out troubled processes easily. The system is also expected to reduce percentage of inferior product.

Traceability system is now attracting much attention especially in food industry. Some systems for fresh meat or vegetables are already proposed and implemented. In such systems, Radio Frequency Identification, RFID, tags are used to distinguish each package from others. However these systems are usually independent from general business processes, e.g. ordering, purchasing and stock processes, and therefore the system creates additional process and cost.

In processed food industry, a few traceability systems are successful. First, style and management unit of materials are completely changed in its products. Therefore identification device does not work effectively in manufacturing process. Second, which materials are dispatched into which product is only recorded in production plan or trading information such as ordering or purchasing. The proposed traceability systems are usually independent from them. Third, most of the processed food manufacturers are in the Small and Medium Enterprises, SMEs. Such companies do not have enough investment for ICT. Some of production management processes are still executed manually. Furthermore, production management of the processed food is natively difficult than that of other industries because of its composite production process.

In this paper, first, we proposed a traceability system for processed food industry. The system is characterised with two special features. One is cooperation with Enterprise Resource Planning systems. Traceability information is generated from usual business information such as ordering, purchasing and production control orders. Introduction of the system is expected not only traceability functions but also further business effectiveness caused by ERP system. Second, we proposed Implosion MRP and additional order acceptance function which is a solution for composite production process. We implemented a prototype system of the traceability system and applied 3 weeks data of certain sea food company.

RELATED WORKS

Takeno et al. (1999) surveyed a process of seafood product manufacturing and indicated management problems on manufacturing preparation. They pointed out the manufacturing process becomes the bottleneck of the whole supply chain. Takeno and Sugawara (2002) and Takeno and Sugawara (2003) also made a point of being supply chain design problems on processed seafood from the viewpoint of postponement production. In these works, they valued the importance of freshness. Kikuchi et al. (2004) has proposed material requirements planning support system for seafood processing. In the system, they divide the manufacturing process into blanching and assembly processes. They pointed out difficulties in application of traditional Material Requirement Planning, MRP, which focuses only on assembly process. Furthermore they proposed calculation methodology to blanching process and unified both in the MRP system. With this revised methodology, they found that manufacturing of processed seafood can be effectively operated on production management system. The proposed traceability system is equipped with this methodology. They also confirm that our approaches can be realized as add-on of Enterprise Resource Planning System. This concept becomes an advantage to introduce the proposed traceability system in practice.

Takeno et al. (2000) investigated the practical problems on Electronic Data Interchange, EDI, in the seafood industries and found out difficulties to introduce Information System into these industries. To solve the difficulties, Okamoto et al. (2002) proposed a basic message representation schema on EDI for the complicated production identification. In the message, history of processing and distribution is represented in the tree structure. This concept is extended to Yonezawa et al. (2003) and Takeno et al. (2004a) as XML EDI system. Takeno et al. (2004b) argues application and availability of traceability information at the industries.

To unify all the above works, Takeno et al. (2005) and Horikawa et al. (2005) proposed a three-layered traceability system. They noted basic concept, tracing algorithm and work flow of the system. However, there is little mention of describing prototype system.

THREE LAYERED TRACEABILITY SYSTEM

The proposed system comprises three independent layers: Physical Logistics layer, ERP layer, and Independent Data Management layer. See Figure 1.

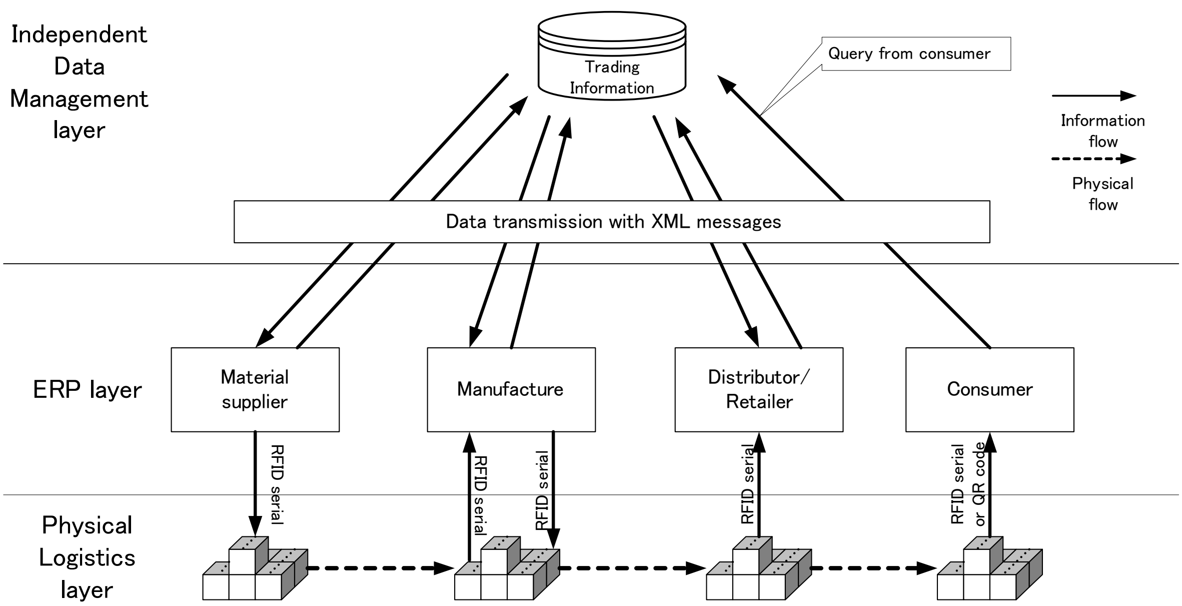

Figure 1 Three layered traceability system.

At Independent data management layer, the entire information is gathered both from ERP layer and Physical logistics layer. Management information including planning and purchasing is obtained from ERP layer, while records of physical movement and shipment are obtained from Physical logistics layer. Traceability information is processed and provided to consumers at this layer. This layer also provides EDI function and tracking information to material suppliers, manufacturers and distributors. The transmitted information is described in XML messages as standard data interchange message format. Functions of this layer will be applicable to B2B e-commerce technology. Because of its independency, it is preferable to be implemented by Application Service Provider, ASP.

Our approach is characterized with data interchange which is not realized within a single layer yet but realized with inter-layers information exchange. Sorting information to be transmitted to another layer and defining boundaries of information sharing tend to create an important design issue.

COMPOSITE PRODUCTION PROCESS

In general, raw materials are disassembled and processed into several parts. The parts, which are manufactured from several different raw materials, are then assembled into one product. The former process to obtain parts is referred to blanching process. The latter is referred to assembly process. We define composite process as a production process comprised of both blanching process and assembly process. Most of products have composite process during their manufacturing process. There is a practical problem for the blanching process to extend the methodologies such as MRP. The proportion of every part or substance involved in raw material is naturally determined. And the proportion is usually different from that of customer's demand. Therefore, to satisfy demand of certain parts, undesired material stock for other products would be generated. For example, a food manufacturer provides croquettes with crab craw. A crab craw and some crabmeat are necessary to produce one croquette. Two craws can be obtained from a crab. To satisfy demand of the croquette, they have to purchase the required number of crabs. If demand of surplus crabmeat is less, the manufacturer is obliged to accept crabmeat as undesired stock.

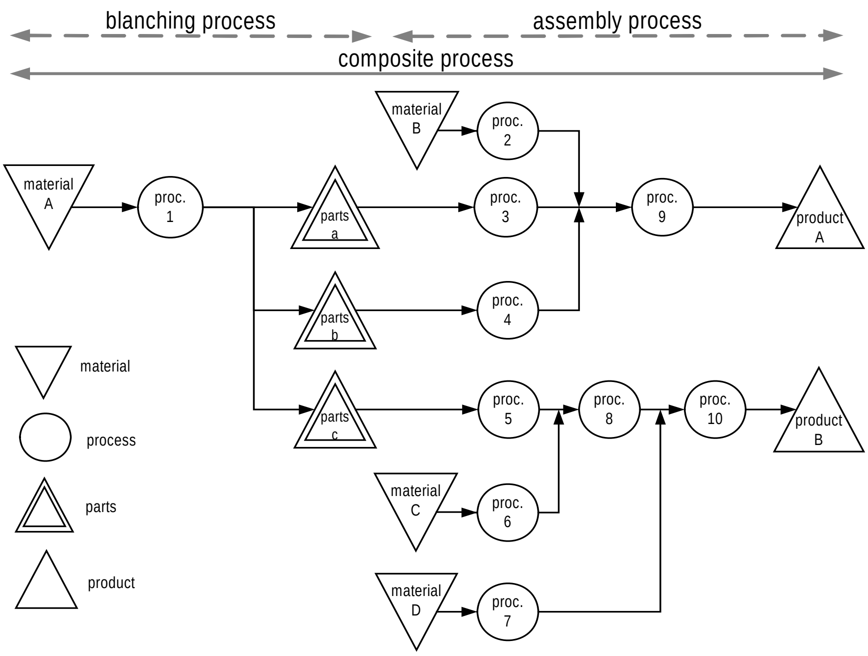

Figure 2 An example of Composite production process.

Figure 2 shows an instance of composite production process. *Material A* is processed into *part a*, *part b* and *part c* through blanching *process 1*. *Part a*, *part b* and *material B* are assembled into *product A* through assembly *process 2*, *3*, *4* and *9*. Product B is also assembled with *part c*, *material C* and *D*.

ADDITIONAL SALES ORDER ACCEPTING

Undesired material/parts stocks are obtained as natural outcome of blanching process. We call it surplus stock. It is important to consume these stocks in the profitable way. Kikuchi et al. (2004) proposed implosion and explosion MRP for composite process. Our approach is based on this and further extended. In the approach, under the cooperative work between sales division and manufacturing division, we introduce re-considering procedure for additional sales order accepting. The system alerts undesired stock in future by visualizing surplus stocks at early stage of production planning. It provides the recommended consumption products for sales division. The function is implemented as a new Decision Support System, DSS, because general ERP packages do not support this. Relation between process and information through the DSS is summarized in Figure 3. The figure shows single iteration of additional sales order acceptance procedure.

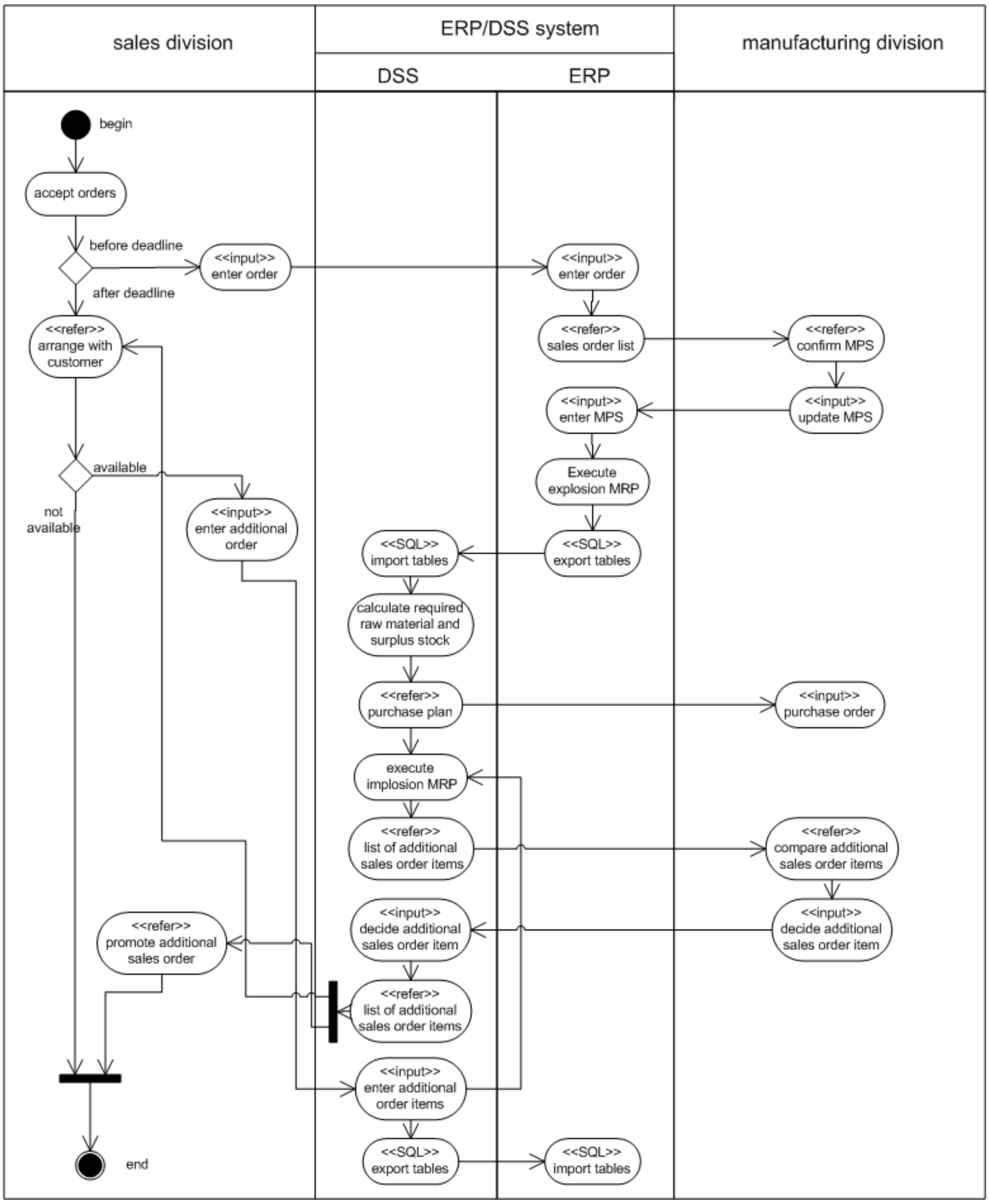

Figure 3 Relations between sales division and manufacturing division.

- MPS and explosion MRP

Master Production Schedule, i.e. MPS, is issued for regular sales orders. Consequently, Material Requirement Planning, MRP, is executed. This MRP is referred to explosion MRP in this paper to distinguish from the proposed implosion MRP. These procedures are general procedure of MRP system. According to outcome of MRP, purchasing order and works order are scheduled in this stage.

- Implosion MRP for excess inventory

Amount of surplus stock is calculated based on outcomes of MRP at manufacturing division. A list of producible product from surplus stock, and material on hand, is calculated with implosion MRP.

- Additional sales order acceptance

Sales division obtains the list and ask customers for additional sales order. If they achieve an order, then necessary materials are assigned to the order. Implosion MRP is executed to update surplus stock for further additional sales order. A new sales order also affects MPS, purchasing order and works orders. The accumulating changes are reflected in ERP package during certain rational time intervals.

- Termination of DSS

DSS terminates if all surplus stocks are assigned or the remaining time is over. DSS is preparing to next term.

PROTOTYPE SYSTEM

We have developed a prototype traceability system for seafood supply chain. The supply chain comprises four material providers, one manufacturer and three distributors. The supply chain provides six frozen seafood products: crab shell gratin, crab craw croquette, crab cream croquette, crab meat fries, crab craw flies and gratin with shrimp and scallop. These products are made from material crab, shrimp and scallop with the recipes from actually existing seafood processing company. See Table 2.

Environment of experimental system

The implemented system consists of Two IA-based Servers, several PCs and 2 RFID scanners. Each device is connected with Ether net Local Area Network, LAN. One server represents ASP server of IDM layer and the other ERP server. Management of XML-DB and Traceability applications are processed on ASP server, while an ERP package, including a relational data base and add-on applications, is executed on ERP server. All applications are implemented as web-based and user's requests are inputted to Client PCs on the LAN. Companies are identified with different DB object at the same ERP server at the prototype system. Two RFID scanners, WELCAT EFG-400-01, are directly connected with Ether net LAN. Further details of experiment environment are shown in Table 1.

Table 1 Details of experiment environment.

Server	Application	
ASP layer	Web Server	Apache 1.3
	XML-DB	Tamino 2.3.1.4
ERP layer	ERP	EFACS E/8 Ver.8.5
	DBMS	MS-SQL 2000
	Web Server	Apache 1.4
	Servelet Container	JBOSS

Table 2 Bill of materials in the experiment.

Level 1			Level 2			Level3		
part id	type	name	part id	type	name	part id	type	name
A0001	MPS	crab shell gratin	B0012	make	crabmeat A	C0001-1	make	crab M
			B0018	make	crabshell S	C0002-1	make	crab S
			B0021	purchase	flour A			
			B0024	purchase	breadcrumb B			
			B0028	purchase	cream sauce			

Level 1			Level 2			Level3		
part id	type	name	part id	type	name	part id	type	name
A0002	MPS	crab craw croquette	B0012	make	crabmeat A	C0001-1	make	crab M
			B0019	make	crabcraw S	C0002-2	make	crab S
			B0021	purchase	flour A			
			B0027	purchase	mashed potato			
			B0028	purchase	cream sauce			

Level 1			Level 2			Level3		
part id	type	name	part id	type	name	part id	type	name
A0003	MPS	crab cream croquette	B0012	make	crabmeat A	C0001-1	make	crab M
			B0024	purchase	breadcrumb B			
			B0027	purchase	mashed potato			
			B0028	purchase	cream sauce			

Level 1			Level 2			Level3		
part id	type	name	part id	type	name	part id	type	name
A0004	MPS	crab meat flies	B0012	make	crabmeat A	C0001-1	make	crab M
			B0020	make	crabcraw M	C0001-2	make	crab M
			B0022	purchase	breadcrumb A			
			B0028	purchase	cream sauce			

Level 1			Level 2			Level3		
part id	type	name	part id	type	name	part id	type	name
A0005	MPS	prawn and scallop gratin with crab shell	B0013	purchase	prawn L			
			B0014	purchase	boiled scallop			
			B0028	purchase	cream sauce			
			B0029	make	crab shell L	C0003-2	make	crab L

Level 1			Level 2			Level3		
part id	type	name	part id	type	name	part id	type	name
A0006	MPS	crab craw flies	B0020	make	crabcraw M	C0001-2	make	crab M
			B0022	purchase	breadcrumb A			
			B0028	purchase	cream sauce			

Implemented experimental system

All developed applications except software of controlling RFID scanners are implemented with web applications. Figure 4, 5 and 6 show snapshots of executed system. At first, users select targeted product from their identification code described in RFID tags, Figure 4. Then traceability information is processed and represented in tree structure, Figure 5. In the figure, all used materials in the targeted product are listed up. Then users can obtain details of certain material used in, Figure 6. This procedure shows trace back scheme. Users can determine products from certain materials.

Figure 7 shows a screen shot of experimental system which shows a list of surplus stocks. From the table, operator recognizes item number and excess amount by date. Figure 8 shows calculation process of implosion MRP. Figure 9 shows final recommended product which consumes surplus stocks with the available number and date.

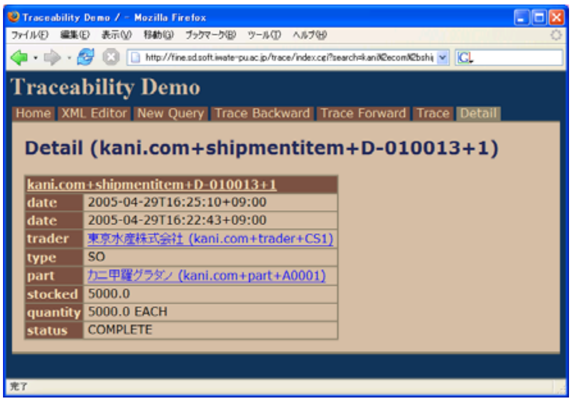

Figure 4 Identification of targeted product.

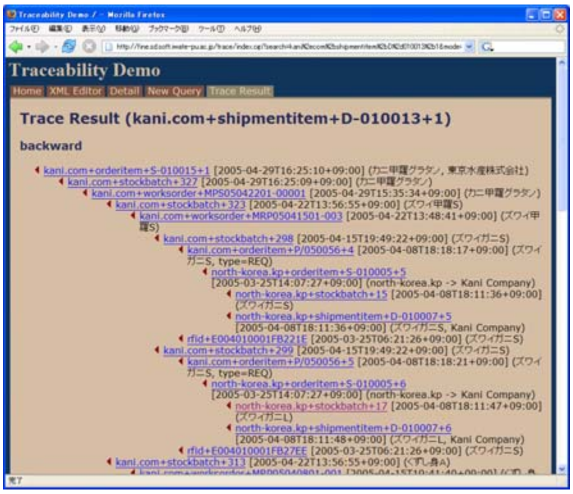

Figure 5 Traceability information represented in tree structure.

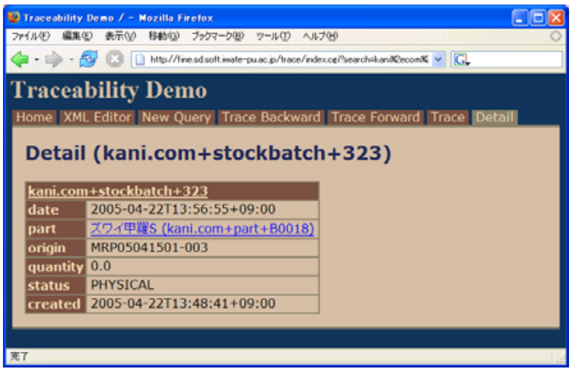

Figure 6 Searched targeted product information.

Figure 7 A list of surplus stocks.

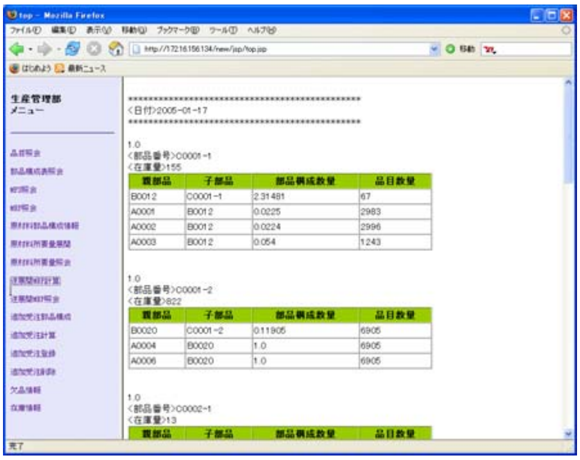

Figure 8 Process of implosion MRP.

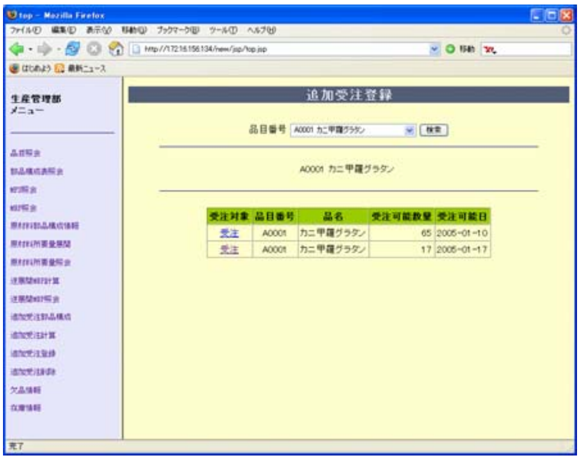

Figure 9 A list of available additional sales order.

CONCLUSION

In this paper, we have proposed traceability system for seafood supply chain. To overcome some problems natively occured in processed food industry, we also extended the system to support composite production process. To support the process, we implemented implosion and explosion MRP module. Composite process naturally causes surplus stocks. The proposed additional sales order acceptance procedure and implemented modules are expected to reduce the stock and improve efficiency of manufacturing function. We are planning to evaluate the proposed procedure and implemented system for evaluation with practical condition and data.

Regulation of releasing information at Independent Data Management layer is not implemented completely. Development of this function is current theme of the research project. In our prototype system, we have tested only one ERP package. Connectivity with different ERP packages in our traceability system is important research themes. At this moment, Electronic Data Interchange functions are simply implemented to refer order item and amount via internet. Extension of this function is also another important developing theme.

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SCM AND TRACEABILITY: ISSUES CONCERNING UTILIZATION OF RFID

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ABSTRACT

It is well known that one of SCM's major objectives is to balance two conflicting goals of management: to remove possibility of running out of stock and to avoid overstocking. Minimizing unnecessary inventory could lead to cost reduction. In its sense SCM is an effective solution to cut cost and to optimize production in quantity. As a manufacturer is confronted with a difficulty that almost all of the efforts in cost-cutting have reached the limits, it is not too much to say that it is the only breakthrough to keep Japanese corporate competitiveness. The effect of optimizing production quantitatively tends to become greater as participating retailers increase, because production process and market demands should be synchronized in order to reduce inventory. So the builder of a network for SCM has to persuade as many retailers as possible to take part in it, and needs to ensure proper benefits to all the participants. In other words, providing some incentive is important when the builder invites retailers to join the SCM network. This study will show that accurate information on the production history and distribution career of goods, especially of food, can be the powerful incentive. But so-called traceability technology whose typical example is RFID is now underdeveloped, that is to say, when a company deploys the technology actually, obstacles exist, including difficulty with accurate tag readings based on the usage environment. In order that the company may use it as the reliable basis of SCM, continuous tests about ratios of the tag read-off in an environment close to actual usage conditions must be conducted. A remarkable case of such an attempt is Dai Nippon Printing's trial. The company opened the "IC Tag SCM Solution Center". It is an experimental facility for logistics management using RFID tags.

INTRODUCTION

As companies of developing countries gain competitive capability in production, an effective long-range strategy for Japanese companies is to convert the basis of competitive advantage from the traditional factors such as capital, equipments, and manual labor into the other factor, while SCM is quite effective on optimizing production. Therefore it can safely be said that SCM is the best way to keep competitive advantage of the Japanese companies. The effect of optimizing production in quantity has a tendency to become greater as participating retailers increase. So the builder of a network for SCM must persuade as many retailers as possible to take part in it, and needs to ensure proper benefits to all the participants. This study will show that accurate information on the production history and distribution career of goods, especially of food, can be a powerful incentive for the retailers, because securing food safety has been one of the major concerns for many consumers. But so-called traceability technology whose typical example is RFID (Radio Frequency Identification) is now underdeveloped, that is to say, when a company deploys the technology actually, obstacles exist, including difficulty with accurate tag readings based on the usage environment. In order that the company may use it as the reliable basis of SCM, the manufacturer of the RFID tag must conduct continuous tests about ratios of the tag read-off in an environment close to actual usage conditions. This paper shows Dai Nippon Printing's trial as a remarkable case of such an attempt.

EFFECT OF SCM ON INVENTORY AND PRODUCTION

It is well known that one of SCM's major objectives is to balance two conflicting goals of management: to remove possibility of running out of stock and to avoid overstocking. Minimizing unnecessary inventory could lead to cost reduction. In its sense SCM is an effective solution to cut cost and to optimize production in quantity. As Japanese manufacturers are confronted with a difficulty that almost all of the efforts in cost-cutting have reached the limits, it is no exaggeration to say that it is the only breakthrough which keeps Japanese companies' competitiveness and promises their success in the future. The effect of optimizing production quantitatively tends to become greater as participating retailers increase, because production process and market demands should be synchronized in order to reduce inventory (Christopher,1997;Beech, 1999), and the synchronization can never be achieved without a consistent management and commonage of information in the production/distribution chain from top to bottom (GISPRI, 2005). So the builder of a network for SCM has to persuade as many retailers as possible to take part in it, and needs to ensure proper benefits to all the participants. In other words, providing some incentive is important when the builder invites retailers to join the SCM network, and it is to form a ‘win-win relationship’ in the supply chain as a result.

TRACEABILITY OF FOOD

Japanese consumers' faith in the safety of their food has been shaken recently, partly due to the spread of new diseases like BSE and avian flu, which has certainly aroused a kind of social unrest. Securing food safety has been one of the top concerns for many consumers lately in such a context. It is a big change in the environment surrounding logistics and retail business. At present there is a high demand for food traceability that can provide retailers and consumers some accurate information on the production history and distribution career of food. In addition, retailers generally hope to grasp how widely the damage has been spread, quickly after the cause has been found when a food accident occurs (Ubiquitous ID Center, 2004). Accordingly, if the builder of a network for SCM realizes food traceability there, it will increase the retailers which take part in it. In other words, historical data concerning foods to ensure safety is a powerful incentive for the retailers to join the SCM network.

SCM AND RFID

In a ubiquitous network society, as computers automatically identify the locations of various things in the real world and perform processing of information concerning specific items and location data, the function to identify physical objects in the real world is considered as a must. For these purposes, the ubiquitous ID technologies give unique numbers, namely ubiquitous codes (ucodes for short) to every physical object. If ucodes are given to every single physical object, it will be possible to manage information that is unique to individual objects even of the same product type, such as when they were made and what delivery route they took. In short, it will realize tracing them (YRP Ubiquitous Networking Laboratory, 2005）. To actualize traceability of various goods, a mechanism that links physical objects with ucodes is required. In the ubiquitous ID technologies, a device that gives ucodes to physical objects is called ucode tag. Currently, RFID tags that support a non-contact communication function and are utilizable as a ucode tag are brought to international attention (Ubiquitous ID Center, op cit.). They have a wide range of applications in distribution, tracing goods and reducing inventories (Nagumo,Nakajima & Okano,2001). Although the RFID tags are very useful in SCM in this manner, they have not yet attained complete traceability. As for almost all of the goods, clothes, shoes, tableware, and parts of a machine, for instance, even if the tracking rate is not one hundred per cent, if it seems to be high enough, retailers are often satisfied with it. But the traceability of food is another matter. The tracking rate under a hundred per cent is meaningless here. Apart from the other goods, as concerns food retailers and consumers demand faultless read-off strongly. Food traceability is an effective incentive for the retailers to join a SCM network, while the builder of the network is forced to keep perfection in tracing food.

DAI NIPPON PRINTING'S TRIAL

In order that a company may use the RFID tags as the reliable basis of SCM, continuous tests about ratios of tag read-off in an environment close to actual usage conditions must be conducted. A remarkable case of such an attempt is Dai Nippon Printing's trial. Dai Nippon Printing (DNP for short) has developed ACCUWAVE series of original RFID tags. They have functions of tracing the production, processing, and distribution of foods, and multi-sensor tags of them make it possible to monitor the products' storage conditions (Dai Nippon Printing, 2005）. In addition, DNP opened the "IC Tag SCM Solution Center" in Itabashi-ward in Tokyo. It is an experimental facility for logistics management using RFID tags. According to our investigation to the DNP's Kansai Department of Packaging and collected materials, the company entered on the gradual introduction of evaluation equipment from 2004, and initiated developing evaluation methodologies for use in specific logistics environments. The company has carried out numerous experiments since that phase, and by building up relevant technologies and know-how has been able to establish simulation test methodologies in a field setting aimed at the introduction of the RFID tags. The foundation of IC Tag SCM Solution Center is the fruit of these efforts. In Japan, with the amendments to the Radio Law Directives, it has become possible to make full use of UHF band in RFID. The objective of the center is to select tag readers and set up the appropriate environment for their use by mocking up specific logistics environments, and conducting RFID tag reader experiments beginning with UHF bands. In this experimental facility they intend to develop traceability systems that are tailored to the environments in which individual items are used, such as agricultural or marine products. Such equipment as conveyor belts, palettes and fork lifts are arranged in the center, making it possible to reproduce the major settings involved in any set of logistics operations faithfully. Making a detailed explanation about the conveyor belts, they use most prevalent forms that comprise belts, rollers, and chains, which allow them to compare the read-off ratios in each different format. The conveyor belts they introduced operate up to 180 meters per minute, the most rapid of any RFID tag testing facility, making it possible to test various factors including speed of passage past the tag reader, the angle of the reader, the position at which the tag is attached to the goods, and the optimal disposition of goods on the conveyor.

CONCLUSION

A certain electrical equipment manufacturer announced on a large scale that they succeeded in developing a prototype for the smallest RFID tag in the world (0.3 sq. mm) , and that tag production efficiency was dramatically increased by employing a design where the electrodes are deployed on the upper and underside of the chip. In such a manner, today many manufacturers of RFID tags are very eager to miniaturize them and to improve their production efficiency strategically. But it is extremely doubtful whether such a strategy is right or not. SCM is quite effective on optimizing production quantitatively. Therefore it is no exaggeration to say that SCM is the only way to keep competitive advantage of the Japanese companies, while traceability of food will become more and more important hereafter in relation to it. To tell the truth, thinking of food traceability, raising the tracing ratio is a matter of great urgency.

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Integrated Models for Multi-level Planning and Scheduling in Supply Chain

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ABSTRACT

Production planning and scheduling (PPS) is one of the core functions in the management of manufacturing industries and its importance is further emphasized by the growing attention focused on supply chain management.

Most of the many studies on PPS have adopted a multi-phased, hierarchical approach in which the production plan is generated at high level, and then the schedule is generated at detailed level. One of the major problems of this approach is that it does not guarantee a feasible schedule with a given production plan. To resolve these limitations, many researchers have tried to integrate the planning and scheduling problems. However, these studies have also suffered limitations due to their intrinsic characteristics and the method for incorporating the hierarchical product structure into the scheduling model.

In this paper we present a new integrated model for PPS based on the lot sizing approach, which we term the Job-based Multi-level lot sizing and Scheduling Model (JMSM). Unlike previous lot sizing approaches, detailed scheduling constraints and practical planning criteria are incorporated into our model. We address a mathematical formulation, propose heuristic solution procedures, and demonstrate the performance of our model by comparing the experimental results with those of other traditional and integrated approaches.

Keyword: production planning and scheduling, supply chain management, lot sizing and scheduling, benchmarked genetic algorithm

INTRODUCTION

Production planning and scheduling (PPS) is one of the core functions in the management of manufacturing industries and its importance is becoming more emphasized by the increasing complexity of the processes to manufacture final products from raw materials and also by the growing attention directed toward supply chain management.

In traditional PPS approaches, a plan for the general attributes of production activities, e.g. the levels of input resources, the rate of production of final products and assemblies, is generated first, after which a detailed schedule is generated with the given production plan. A Master Production Schedule (MPS) is first derived, release dates are then computed through Material Requirement Planning (MRP) which eventually should cooperate with Capacity Requirement Planning (CRP) to resolve resource capacity constraints, and finally a schedule is determined. Sometimes, interactions between these different decision levels are taken into account (Dauzère-Péres et al., 1994). Figure 1 shows the typical Manufacturing Planning and Control (MPC) system, which is divided into three phases: front end, engine and back end (Vollmann et al., 2005). Moreover, capacity planning is also separated from material planning and scheduling.

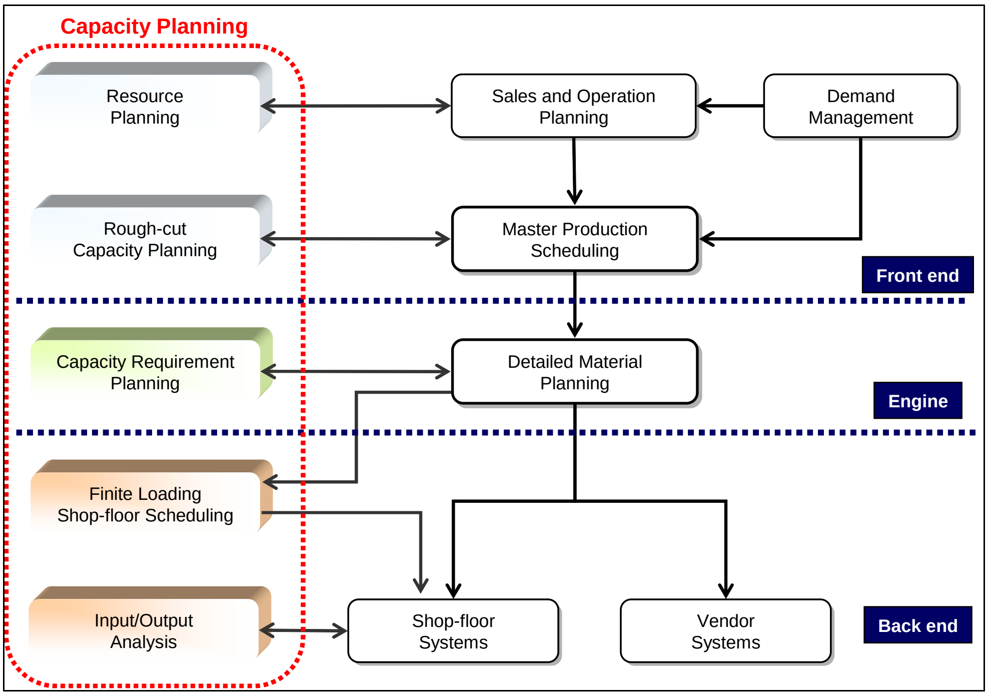


Figure 1. Hierarchy and Decomposition in the Typical MPC System

One major problem of this traditional hierarchical and decomposed approach is that it does not guarantee the existence of a feasible production schedule for the given production plan by ignoring the detailed scheduling constraints at the planning level. Some products are not completed before their due dates. On the contrary, while capacity constraints are satisfied, it could generate an expensive plan which requires excessive inventory (including WIP) or setup cost.

In order to reduce the disadvantages arising from decomposition, several papers have tried to integrate the PPS. However, they also suffer some limitations due to their intrinsic characteristics such as the determination of the size of reduced time buckets or the problems in incorporating the detailed hierarchical product structure into the scheduling model.

In this paper, we present a new integrated model for multi-level planning and scheduling based on a lot sizing approach, which we term the Job-based Multi-level lot sizing and Scheduling Model (JMSM). Unlike previous simultaneous lot sizing and scheduling approaches, detailed scheduling constraints and practical planning criteria are incorporated into our model respecting the multi-level precedence constraints among the items. For example, due dates, make-span, transportation time and costs of inventory holding, setup and backlogging are incorporated into our model through a special data structure. We present a mathematical formulation and also propose heuristic solutions to the problem. Finally, the performance of our model is compared to the optimal solution and other traditional approaches.

The paper is organized as follows. Section 2 presents a literature review and section 3 the concept of the JLSP and mathematical formulation. A heuristic for our model is discussed in section 4, computational simulations are performed in section 5, and the conclusion is presented in section 6.

LITERATURE REVIEW

Many researchers have tried to integrate the PPS problems as the available computing power increases. Those studies can be classified into two groups: one is based on lot sizing with smaller bucket size and the other is based on job shop scheduling which gives a very large scale optimization problem.

First, the approaches based on lot sizing focus on the problem of determining the sequence and size of production lots. Several types of lot sizing and scheduling models are well-known: the Discrete Lotsizing and Scheduling Problem (DLSP), Proportional Lotsizing and Scheduling Problem (PLSP), and General Lotsizing and Scheduling Problem (GLSP) (Fleishmann, 1990; Drexl et al., 1995; Kimms et al., 1998; Fleishmann et al., 1997).

These lot sizing models conduct the scheduling by subdividing the planning period unit (macro-period) into several small periods (micro-period) such as days or shifts, or even hours. Because one or two items can be produced per period, the sequence for the lot is determined by the planning result in each period (Fleishmann, 1990; Drexl et al., 1995). However, in real world problems, the number of periods is restricted, and the increment in the number of periods leads to large-sized models (Drexl et al., 1997; Karimi 2003). For example, when the macro-period week is broken into the micro-period days, the problem size is multiplied by at least 5. To avoid this problem, Jordan and Drexl (1998) solved the DLSP as a batch sequencing problem (BSP), but they did not consider the multi-level product structure and backlogging jobs. While Fandel and Stammen-Hegene (2006) developed a model for multi-product and multi-level production, they could solve only small-sized problems with a small number of products and macro-periods because of their model's complexity.

Second, the approaches based on job shop scheduling tried to integrate the lot-sizing and scheduling problem in the job-shop scheduling environment. These models have integrated precise capacity constraints including the sequencing of products on the machine. Lasserre (1992), Dauzère-Péres and Lasserre (1994) addressed the integrated lot-sizing and scheduling problem, and proposed a two-level, iterative procedure to compute the best possible schedule in a job-shop environment. Anwar and Nagi (1997) proposed a two-phase heuristic for a general job-shop that produces complex assemblies. In the first phase, the proposed heuristic schedules operations by exploiting the critical path to minimize the makespan on a lot-for-lot basis. In the second phase, the heuristic

iteratively groups orders to obtain lot-sizes that further reduce the makespan, setup and holding cost.
These methods tend to focus on the makespan-based scheduling level rather than cost-based planning level. Due to the complexity caused by the consideration of excessively detailed operations, they only provided a good or feasible solution for their model without any results of a comparison with the optimal solution for the solution quality or computational time. Furthermore, a multi-period planning horizon was not considered.

As mentioned above, both these approaches suffer limitations due to their intrinsic characteristics such as the determination of the size of reduced time buckets or the problems in incorporating the detailed hierarchical product structure into the scheduling model. Moreover, little research has been conducted into simultaneous lot sizing and scheduling for multi-product, multi-level production.

In order to overcome these shortcomings, scheduling constraints such as due dates, setup time, processing time and transportation time are considered with practical planning criteria such as the costs of inventory holding, setup and backlogging. Each demand over the period is converted into a specific job, which reduces the problem to merely similar to a scheduling problem. By sequencing and adjusting the jobs, the lot sizing and starting/completion times of the jobs are determined simultaneously. Thus detailed constraints are easily considered without breaking the planning periods into smaller periods such as day and hour. JMSM also considers the multi-level BOM structure and incorporates more detailed costs such as backlogging cost. Detailed procedures are described in section 3.2.

PROBLEM FORMULATION

Problem assumptions

We consider the supply chain environment in which multi-level, multi-products are produced in multi-facilities. The deterministic models to be considered are based on the following assumptions. The number of different items or components have to be manufactured on a work center while satisfying the capacity constraint: j = 1, . . . , J. The time horizon is segmented into a finite number of equal length time periods: t = 1, . . . , T. Demand d_{ij}, for item j in period t has to be satisfied and allows backlog. The setup cost sc_j for item j is incurred whenever the production of a batch starts with item change. The time to produce one unit of item j is pt_j. The holding cost hc_j and backlog cost bc_j per unit and period of item j are identical for all periods.

index:

j = 1, ……….., J items

t = 1, ……….., T periods

n = 1,……….., Nj jobs of item j

data:	
d_{jt}	the demand quantity in period t
pt_j	the processing time of item j
st_j	the setup time of item j
tt_{ij}	the transportation time of item i to successor item j
sc_j	the setup cost of item j
hc_j	the holding cost per period of item j

Procedure

The basic concept of our JMSM is the incorporation of capacity constraints such as due date in the scheduling level into the planning level.

First, demands over periods are converted into jobs which have the due date, setup time and processing time. Job is symbolized as J_{jn}, which means that the job produces item j and the nth positive demand over periods, while d_{ij} is the demand of the item j in period t. Zero-demand is ignored. Due date is set to the end of the period in which demand is needed. The setup time is the same as one unit setup time, and the processing time of the job is calculated by multiplying the quantity of demand by the time to produce one unit of item j. The holding and backlog cost of each job per period is obtained by multiplying the quantity of demand by the unit holding cost per period.

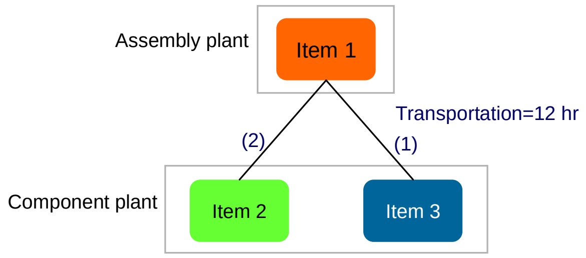
job information:	
J_{jn}	job which the n*th* positive demand of item j in period t is converted into. Only positive demand is considered J_{jn} is corresponding to the demand d_{jt}
q_{jn}	the demand quantity for J_{jn}
dt_{jn}	due date of J_{jn} : due time for delivery
pt_{jn}	processing time of J_{jn} : $q_{jn} \times pt_j$
hc_{jn}	holding cost of J_{jn} : $q_{jn} \times hc_j$
bc_{jn}	backlog cost of J_{jn} : $q_{jn} \times bc_j$

Next, the job is sequenced and lot sized according to the following scheduling constraints:

a) The job of the next period for the same item cannot start until that of the previous period is finished.
b) If jobs of the same item are sequenced successively even though machine has idle time between jobs, the jobs are combined into the same lot.
c) If jobs with the same item are produced successively, the jobs are lot sized and have only one setup at the beginning of the first job.
d) To respect the precedence between the different production levels, the job of the successor must scheduled by the job of the predecessor with the transportation time delayed.

The following example with 2-level product structure, including J=3 items, is illustrated. Figure 2 presents the item structure and production information for the example. The capacity of the machine is C=24 (hours) for each period t = 1, . . . , 10.

Product structure



Production data

Product	Operation	Work center	st_j	pt_j	sc_j	hc_j	bc_j	tt_{ij}
item 1	1 of 1	A	5	2	1200	4	16	
item 2	1 of 1	B	5	0.5	500	2		12
item 3	1 of 1	B	10	1	1000	2		12

MPS

Period	1	2	3	4	5	6	7	8	9	10
Item 1			10		10		20	5		15

Figure 2. Data for 2-level example

The first step in the procedure is to convert the demands into jobs. In figure 2, d_{13}, demand for item 1 in period 3, is converted into J_{11}, the first job for the item 1. Due date is set to period 3 (=3*24 hours), setup time is 5 hours, processing time is 20 hours (=2 hours*10 units) and holding cost is 960/period (=4 * 10 units * 24 hours).

In the sequencing step, we can generate the feasible solution by sequencing the jobs without overlapping jobs. Since the sequences among jobs for the same item are already determined, we only consider the sequences of jobs competing for a sharing work center.

Through the adjusting step, the starting/completion time for each job is determined by considering the setup time, transportation time and lot sizing. Jobs for the item 1, J_{12}, J_{13}, and J_{14} are scheduled successively thus setup time and setup cost are occurred only for J_{12}. Each job is scheduled on an exact starting/completion time, and could be distributed among periods without further setup. By offsetting the transportation time, the precedence relationship between different levels can be easily considered. Because transportation time between items 1 and 2 is 12 hours, the completion time of J_{21} must be scheduled earlier 12 hours earlier than the starting time of J_{11}.

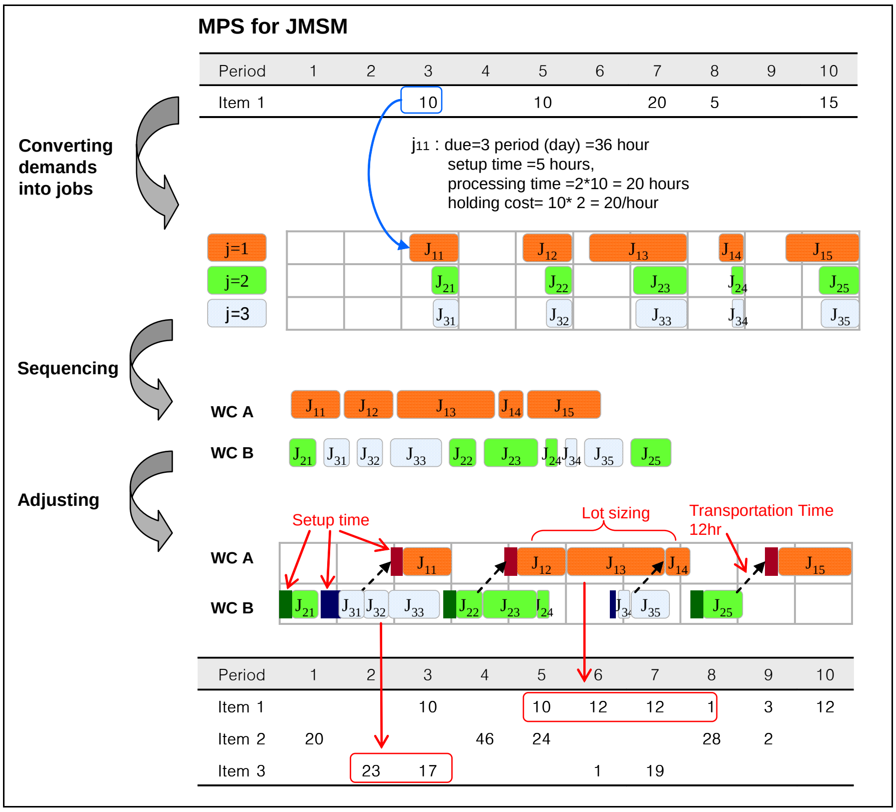


Figure 3. Example of the JMSM process

The starting/completion time of jobs is basically adjusted by backward scheduling with meeting the due date. However, this may result in an infeasible solution, which means that the starting of the first job is before period 0. To make it feasible all the related jobs are shifted by forward schedule, which may cause the backlogging of jobs. In figure 4, the starting time of J31 is before period 0. Thus we must shift the related jobs such as J_{31}, J_{32}, J_{21}, J_{33} and J_{22} forward, which also postpones the successor jobs such as J_{11}, J_{12} are also postponed. As result, the schedule becomes feasible but J_{11} and J_{12} become backlogged. If the production capacity is insufficient, backlogged jobs are unavoidable.

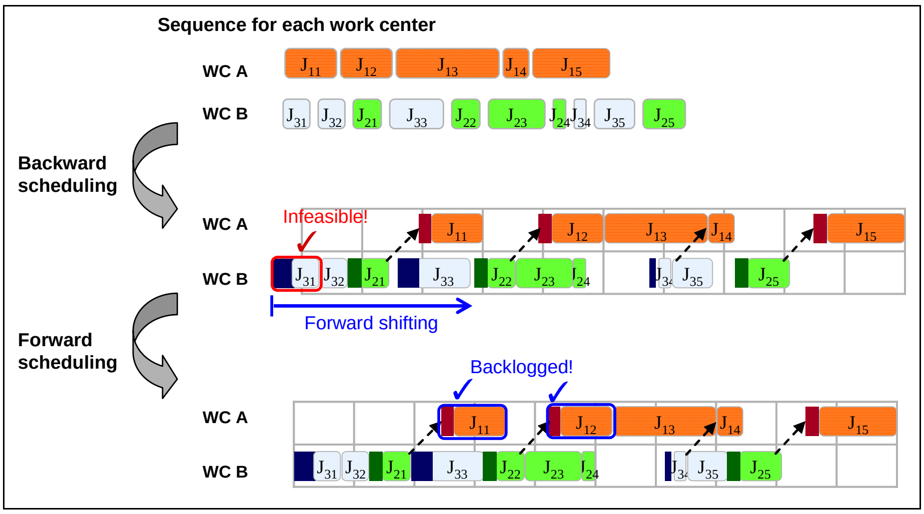


Figure 4. Adjustment of jobs

Model Formulation

The following mixed-integer model gives a precise specification for the JMSM problem. This model is based on the disjunctive constraint integer programming formulation to the classic job shop problem which relies on indicator variables to specify operation sequence.

decision variables:

S_{jn}	the starting time of J_{jn}
C_{jn}	the completion time of J_{jn}
$Y_{j'n'\circ jn\circ w}$	1 if $J_{j'n'}$ comes before J_{jn} on sharing work center w and 0 otherwise
$Z_{j,n+1}$	1 if J_{jn} and $J_{j,n+1}$ are processed successively with not interruption of other jobs
E_{jn}	the difference between the completion time and due date of J_{jn} $\max\{0, dt_{jn} - C_{jn}\}$
L_{jn}	the difference between the completion time and due date of J_{jn} $\max\{0, C_{jn} - dt_{jn}\}$

Minimize $$\sum_{j=0}^{J}\sum_{n=0}^{N}(sc_j \times Z_{jn} + hc_j \times q_{jn} \times E_{jn} + bc_j \times q_{jn} \times L_{jn}) \quad \textbf{(1)}$$

Subject to:

$$S_{jn} + st_j Z_{jn} + pt_{jn} = C_{jn} \qquad \forall j,n \quad \textbf{(2)}$$

$$C_{jn} \le S_{j,n+1} \qquad \forall j, n = 1,\ldots,N_j - 1 \quad \textbf{(3)}$$

$$C_{jn} + H \times Z_{j,n+1} \ge S_{j,n+1} \qquad \forall j, n = 1,\ldots,N_j - 1 \quad \textbf{(4)}$$

$$S_{j'n'} - C_{jn} + H(1 - Y_{jn\circ j'n'\circ W}) \ge 0 \qquad \forall j,n \quad \forall j',n' \quad j \ne j' \quad J_{jn}, J_{j'n'} \in W \quad \textbf{(5)}$$

$$S_{jn} - C_{j'n'} + H \times Y_{jn\circ j'n'\circ W} \ge 0 \qquad \forall j,n \quad \forall j',n' \quad j \ne j' \quad J_{jn}, J_{j'n'} \in W \quad \textbf{(6)}$$

$$S_{jn} - C_{in} - tt_{ij} - E_{in} = 0 \qquad \forall i,j \quad j \in S(i)\text{: item j is successor of item i} \quad \textbf{(7)}$$

$$E_{jn} \ge d_{jn} - C_{jn} \ge 0 \qquad \forall j,n \quad j \in F \quad \text{: item j is finished goods} \quad \textbf{(8)}$$

$$L_{jn} \ge C_{jn} - d_{jn} \ge 0 \qquad \forall j,n \quad j \in F \quad \textbf{(9)}$$

$$Z_{jn} \in \{0,1\} \qquad \forall j,n \quad \textbf{(10)}$$

$$Y_{jt\circ j'n'\circ W} \in \{0,1\} \qquad \forall j,n \quad Job_{jn}, Job_{j'n'} \in W \quad \textbf{(11)}$$

$$S_{jn}, C_{jn} \ge 0 \qquad \forall j,n \quad \textbf{(12)}$$

The objective function (1) is to minimize the sum of setup, holding and backlogging costs. Holding cost is incurred when the job is completed early and backlog cost is occurred when the jobs is finished later than the due date. Equations (2) represent the relation between the starting time and completion time for the same job. Inequalities (3) state that the jobs cannot start until the previous period jobs are finished. Due to the restrictions (4), production setup can take place only in the first job when the jobs are produced successively. The inequalities (5) and (6) capture the disjunctive constraints, which decide which job among the different items j and j' is processed first.

If $Y_{j'n' \circ jn \circ W} = 1$, inequalities (5) and (6) are represented as followings:

$$S_{jn} - C_{j'n'} \geq 0 \qquad (13)$$

$$S_{j'n'} - C_{jn} + H \geq 0 \qquad (14)$$

Thus, $J_{j'n'}$ is comes before J_{jn} on work center W, and is 0 otherwise. Equalities (7) represent the precedence between the different production levels. Transportation time and earliness are considered. Inequalities (8) say that job J_{jn} is completed before due date, so inventory is held until the products are delivered. The inequalities (9) represent the lateness of the job, which means that jobs are backlogged. Constraints (10) and (11) define the binary variables. Non-negative conditions are considered in constraints (12).

THE BENCHMARKED GENETIC ALGORITHM (GA)

Solution representation

To design a genetic algorithm (GA) for a particular problem, we first need to devise a suitable representation scheme that shows the solution characteristics. To solve our JMSM, we have to decide the sequence of jobs firstly and then adjust the starting/completion time. The sequence of jobs is represented by the following chromosome for each work center.

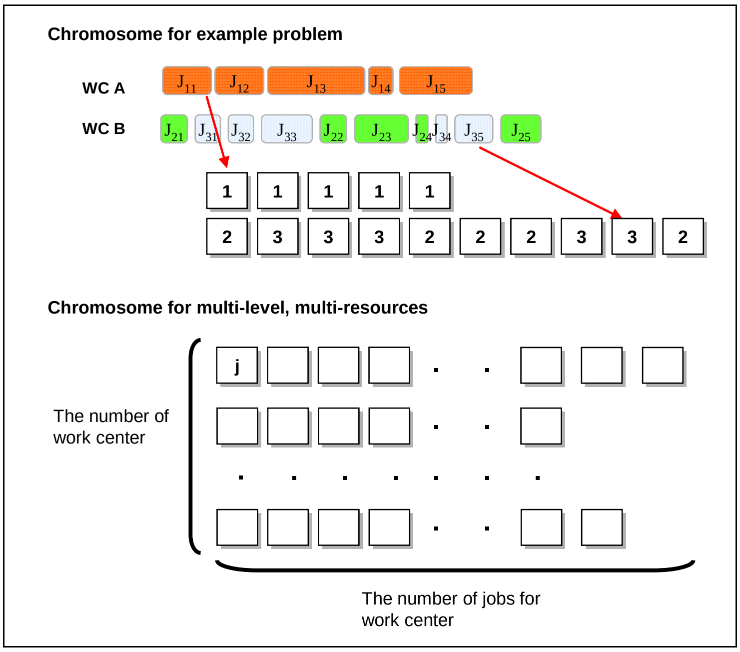


Figure 5. Chromosome for GA

The procedure of benchmark GA

Figure 6 shows the procedure of our proposed algorithm. In the first step, a number of genetic populations are generated, each of which has gene information which represents a specific solution for a given problem. This gene information is improved to generate a high quality solution through a selection, crossover, mutation and local refinement procedure (Berretta et al., 2004). We can facilitate the improvement through the local refinement procedure by benchmarking the current best chromosome. Whenever the meme information of each chromosome is considered convergent, some of the chromosome is replaced by new chromosome whose gene information is generated randomly. This avoids falling in the local optimum. These procedures are iterated until they meet the termination criterion. In the next subsection, we explain each procedure in more detail.

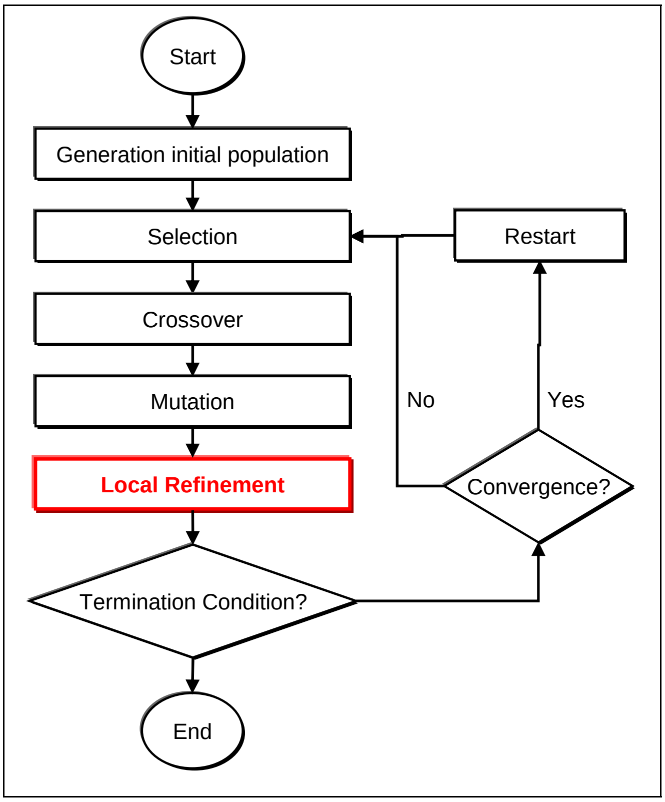


Figure 6. The procedure of the benchmark GA

Local refinement procedure

We devise the chromosome through the local refinement by benchmark procedure. This is the most important procedure in our proposed algorithm. Lot sizing is a trade-off between setup costs and holding costs. Increasing the lot size increases the average amount of inventory on one hand, but on the other reduces the frequency of setup. Therefore, we use this concept as a refinement procedure using the benchmark. Figure 7 shows the refinement procedure using the number of setups, which is controlled by re-arranging the sequencing. This procedure eliminates the setup cost of job J_{35} , which is greater than the holding cost and backlogging cost occurred in job J_{25}, and thus improves the solution.

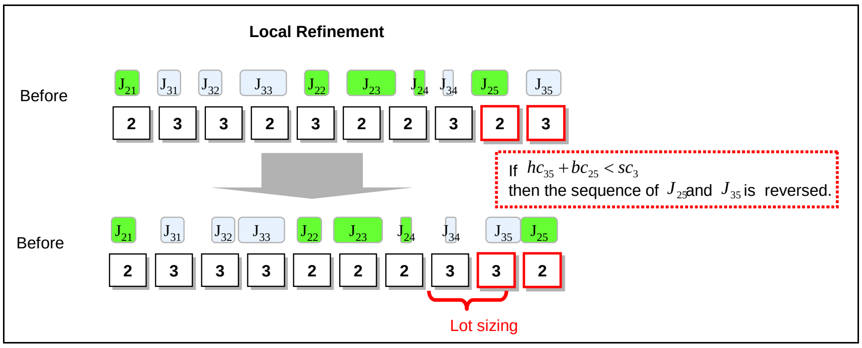


Figure 7. Local refinement

Figure 8 shows the refinement algorithm using the number of setups at the level of each item.

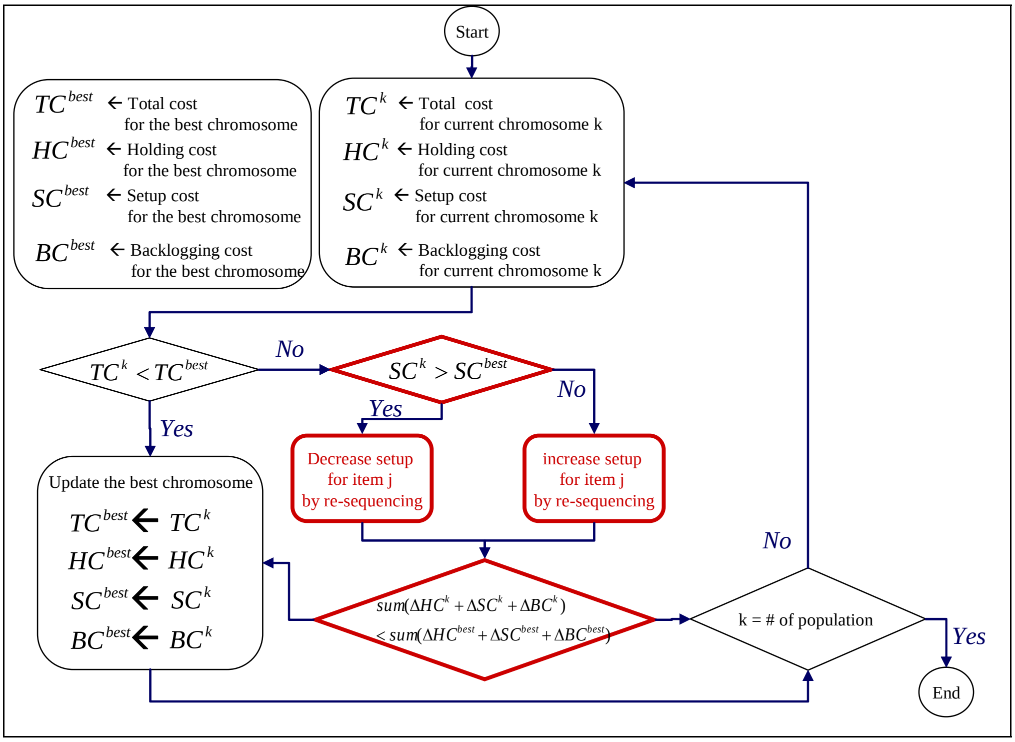


Figure 8. Local Refinement benchmarking the costs of setup/holding/backlogging

COMPUTATIONAL COMPARISION

Experimental design

Due to the difficulty of obtaining optimal solutions for multi-level product structures, we limited the study to a performance comparison for the selected specific problem sets. The individual problems were generated by combining i) the size of the problem, ii) the commonality index (C value) and iii) the time between order (TBO) value. The size of the problem was determined by the depth of the supply chain, the number of items and the length of the planning horizon. The C value is defined as the average number of successors per component (Collier 1981; Kimms, 1997):

$$C = \frac{A - A_{\min}}{A_{\max} - A_{\min}} \qquad (15)$$

Let h and D be the inventory holding cost and the average demand for the item being considered, respectively. TBO can be used to deduce the set-up cost in the following way.

$$TBO = \sqrt{\frac{2s}{hD}} \rightarrow s = \frac{TBO^2 \cdot h \cdot D}{2} \quad \text{--} \quad (16)$$

We tested our benchmark GA about four sizes of experimental instances as following table 1. We created 3 instances for each experimental set randomly.

Experimental set	The depth of BOM level	# of product	# of period
Small size	2	5	10 / 15
Medium size	3	10	10 / 15
Large size	3	20	10 / 15

Table 1. Experimental sets of instances

We compared the above experimental sets with the optimal solution or traditional methods as follow:

- ☐ BGA: our benchmarked GA
- ☐ CP-OP: Optimal solution by CPLEX 9.0
- ☐ CP-UB: Upper and Lower Bound by CPLEX 9.0
- ☐ MCS: MRP + CRP + Scheduling

Simulation result

The tables show the experimental results of each problem sets. Time is represented in second. For small-sized problem (SS-10, SS-15), we found the optimum value using CPLEX. However for the middle- and large-sized problems the computing time required to calculate the optimal value was excessive and we therefore allowed a tolerance within 10%~20% between upper and lower bounds. For the practical problem, only BGA and MCS are compared.

Period	BGA		CP-OP			MCS	
	Time	Value	Time	Value	Gap[a]	Value	Gap[b]
SS-10	212	16,032	62	15,428	-3.77%	21,687	35.27%
SS-10	250	16,905	60	16,315	-3.49%	21,505	27.21%
SS-10	243	15,495	45	15,130	-2.36%	19,840	28.04%
SS-15	290	28,127	121	26,715	-5.02%	34,120	21.31%
SS-15	315	31,052	680	28,884	-6.98%	38,425	23.74%
SS-15	305	30,100	760	29,904	-0.65%	41,020	36.28%

$Gap^a = (Value_{CP\text{-}OP} - Value_{BGA}) / Value_{BGA}$

$Gap^b = (Value_{MCS} - Value_{BGA}) / Value_{BGA}$

Table 2. The results of small-sized instances

Period	BGA		CP-LU (10% gap)				MCS	
	Time	value	Time	UB	LB	Gap[c]	value	Gap
MS-10	248	11,864	1,066	11,724	10,520	-6.25%	18,352	54.69%
MS-10	289	12,496	4,550	12,669	11,373	-3.80%	18,466	47.78%
MS-10	330	12,677	5,586	12,871	11,528	-3.77%	19,120	50.82%
MS-15	420	22,426	16,456	21,462	19,258	-9.21%	31,590	40.86%
MS-15	452	20,168	21,290	20,065	18,012	-5.60%	28,860	43.10%
MS-15	540	24,576	18,640	24,407	21,860	-5.87%	31,640	28.74%

$Gap^c = \{ (UB_{CP\text{-}LU} + UB_{CP\text{-}LU})/2 - Value_{BGA} \} / Value_{BGA}$

Table 3. The results of middle-sized instances

Period	BGA		CP-LU (20% gap)				MCS	
	Time	value	Time	UB	LB	Gap	value	Gap
LS-10	622	23,425	12,260	24,378	20,315	-4.60%	37,204	58.82%
LS-10	670	25,422	18,415	25,488	21,240	-8.10%	35,420	39.33%
LS-10	818	24,510	23,458	25,274	21,062	-5.47%	36,120	47.37%
LS-15	1,088	26,713	36,450	27,048	22,540	-7.18%	35,816	34.08%
LS-15	1,240	27,450	38,451	27,564	22,970	-7.95%	38,450	40.07%
LS-15	995	28,680	39,540	28,668	23,890	-8.37%	38,652	34.77%

Table 4. The results of large-sized instances

The results show that BGA confirms the good solution that the gap compared with the optimal solution is less than 10% within the reasonable computation time. BGA is better than MCS for all instances at least 20% better than the MCS.

CONCLUSION

In this study, we have dealt with the integrated model for multi-level planning and scheduling. Although the integrated planning and scheduling problem has been studied by many authors, introducing new models and more efficient solution approaches remains a challenging subject. We proposed the new models based on the lot sizing approach, which we termed the Job-based Multi-level lot sizing and Scheduling Model (JMSM). Scheduling constraints such as due dates, setup time, and run time are incorporated into the practical planning criteria such as the costs of inventory holding, setup and backlogging and transportation time. Each demand over the period is converted into a specific job, which reduces the problem to merely similar to a scheduling problem. By sequencing and adjusting the jobs, the lot sizing and starting/completion times of the jobs are determined simultaneously respecting the multi-level precedence constraints among the items. Thus detailed constraints are easily considered without breaking the planning periods into smaller periods such as day and hour. JMSM also considers the multi-level BOM structure and incorporates more detailed costs such as backlog cost.

We developed a heuristic solution procedure based on the concept of benchmarking, which guarantees the evolution of solutions by taking into account the interrelationships among chromosomes. The effectiveness of the proposed algorithm was tested through a series of simulation experiments with various problem sizes. Comparisons among the solutions generated from several simulations are presented.

However, the model and heuristic proposed in this work are not sufficient for practical applications. To be confident about our models and the proposed solution approach, more precise experimental design is required for a better comparison between the algorithms, and a more robust and effective heuristic is needed.

ACKNOLEDGEMENT

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APPENDIX A: EXAMPLE OF MCS

Here illustrated the procedure for MCS (MRP, CRP and scheduling) using the example in figure 2.
For the MRP procedure, the lead time for MRP is required. Lead times are typically made up of four elements:
Processing time: operation or machine run time per piece * lot size
Setup time: time to prepare the work center, independent of lot size
Move time: delay while waiting to be moved plus time spent moving from one work center to the next.
Queue time: time spent waiting to be processed at a work center, which depends on workload and schedule.
Queue time frequently accounts for 80% or more of the total lead time. We assumed that the MRP system is better than normal, and thus set the queue time to approximately 33% of the total lead time as follows:

Product	Operation	Work center	st_j	pt_j	tt_{ij}	MRP Lead time		Min. lot
						Exact time (day)	Rounded time (day)	
item 1	1 of 1	A	5	2		0.94*	1	5
item 2	1 of 1	B	5	0.5	12	1.38	1	10
item 3	1 of 1	B	10	1	12	2.00	2	5

** MRP Lead Time for Item j : exact time (day) =* $(pt_j \times lotsize + st_j + tt_{ij}) \times 1.5 / 24$

Table 5. MRP lead time

MRP gross to net explosion by lot-for-lot lot sizing procedure is shown in figure 9:

Gross to Net Explosion

MPS for MRP

Period	Past due	1	2	3	4	5	6	7	8	9	10
mps				10		10		20	5		15

Gross to net explosion

Item 1	Past due	1	2	3	4	5	6	7	8	9	10
MPS				10		10		20	5		15
Planned order				10		10		20	5		15
Order release			10		10		20	5		15	

Item 2	Past due	1	2	3	4	5	6	7	8	9	10
Gross req.			20		20		40	10		30	
Planned order			20		20		40	10		30	
Order release		20		20		40	10		30		

Item 3	Past due	1	2	3	4	5	6	7	8	9	10
Gross req.			10		10		20	5		15	
Planned order			10		10		20	5		15	
Order release	10		10		20	5		15			

Figure 9. Gross to Net Explosion

CRP utilizes the time-phased material plan information produced by an MRP system. The capacity needed to complete the work is considered in calculating the required work center capacities using the resource profile procedure.

Work center Capacity Requirements Using CRP

Work center A

period	Past due	1	2	3	4	5	6	7	8	9	10
Planned Order (item 1)			10		10		20	5		15	
Capacity Requirements (Hours)			25*		25		45	15		35	

Work center B

period	Past due	1	2	3	4	5	6	7	8	9	10
Planned Order (item 2)		20		20		40	10		30		
Planned Order (item 3)	10		10		20	5		15			
Capacity Requirements (Hours)	20	15	20	15	30	40	10	25	20		

* *Capacity requirement (hours)*= $\sum_j \left\{ pt_j \times (planned \quad order) + st_j \right\}$

Figure 10. CRP calculation

CRP calculates only capacity needs: it makes no adjustments for infeasibility. As shown in figure 11, these are depicted in either a CRP or infinite workload. The work of past due is scheduled in period 1 in the finite scheduling approach. To solve the capacity problem, we use the vertical loading, where a work center is scheduled job by job.

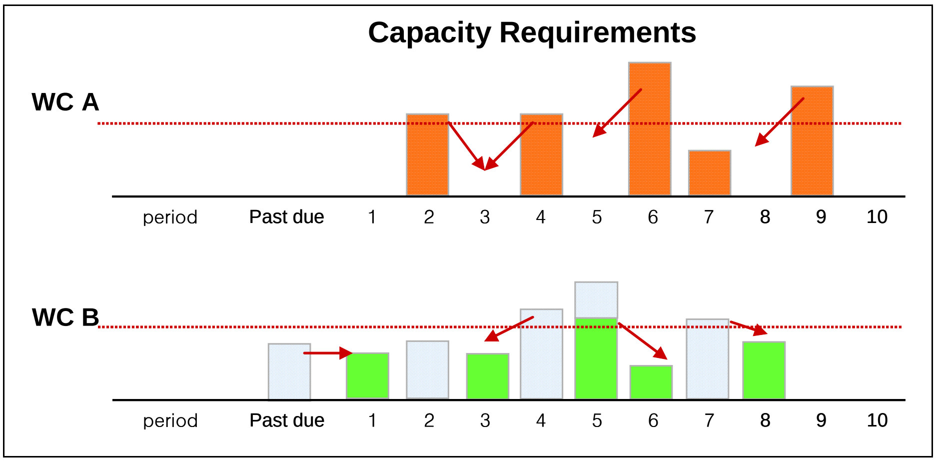

Figure 11. Capacity requirement

The solution is improved by the forward/backward scheduling. The backward scheduling approach starts with scheduling jobs backward from their due dates, where each job is completed as early as possible. If a backward scheduling approach produces a past due start date for a shop order, this indicates infeasibility. In this case, the whole schedules are shifted forward to be feasible. The bottom portion of figure 12 shows the result of the finite loading and scheduling.

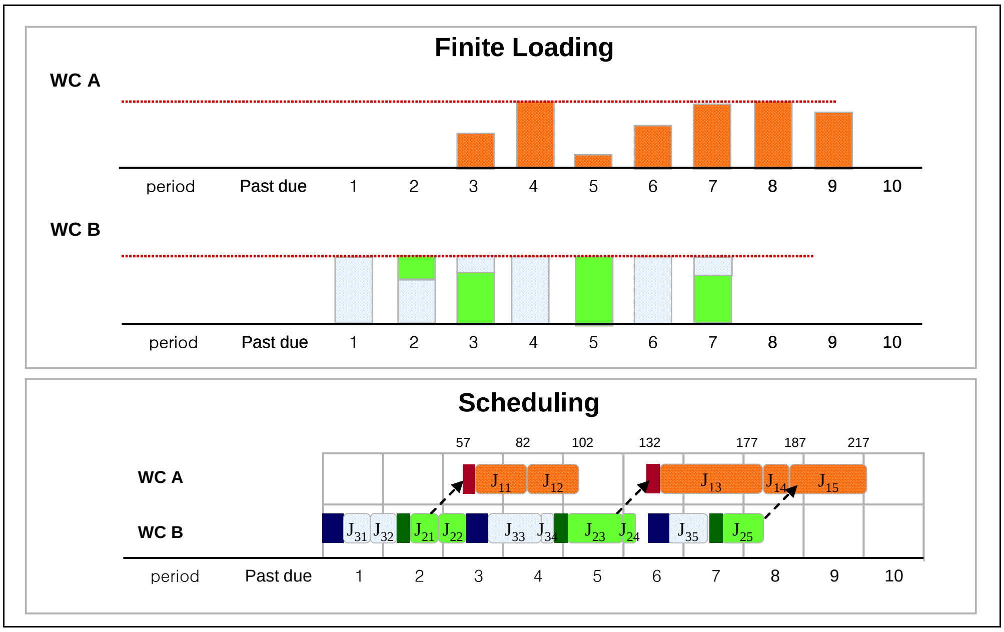

Figure 12. Finite Loading and Scheduling

The detailed result of MCS is presented in table 6:

item 1	demand	stj	ctj	due(hours)	scj	hcj	bcj
1	10	57	82	72	1200		800
2	10	82	102	120		720	
3	20	132	177	168	1200		1440
4	5	177	187	192		100	
5	15	187	217	240		1380	
Sum					2400	2200	2240

item 2	demand	stj	ctj	due(hours)	scj	hcj	bcj
1	20	30	45	45	500	0	
2	20	45	55	70		300	
3	40	90	120	120	500	0	
4	10	120	125	165		400	
5	30	155	175	175	500	0	
Sum					1500	700	0

item 3	demand	stj	ctj	due(hours)	scj	hcj	bcj
1	10	0	20	45	1000	250	
2	10	20	30	70		400	
3	20	55	85	120	1000	700	
4	5	85	90	165		375	
5	15	130	155	175	1000	300	
Sum					3000	2025	0

Table 6. Result of scheduling of MCS

The objective function value is $Z_{MCS}=14065$.

APPENDIX B: EXAMPLE OF JMSM

The scheduling result for same example using JMSM is presented in figure 13:

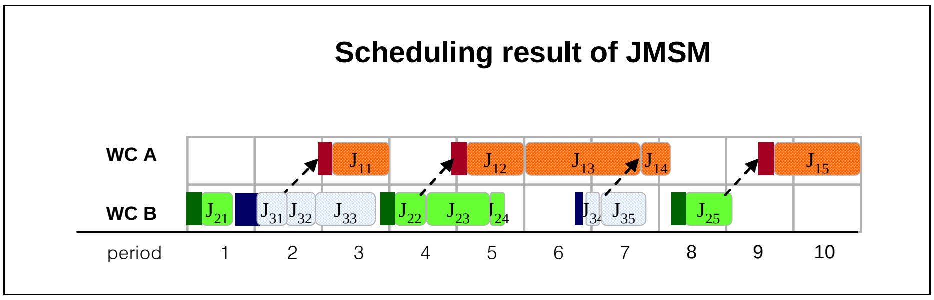

Figure 13. Gantt chart of scheduling result

The detailed result of JMSM is presented in table 7:

item 1	demand	stj	ctj	due(hours)	scj	hcj	bcj
1	10	47	72	72	1200		
2	10	95	120	120	1200		
3	20	120	160	168		640	
4	5	160	170	192		440	
5	15	205	240	240	1200		
Sum					3600	1080	
item 2	demand	stj	ctj	due(hours)	scj	hcj	bcj
1	20	0	15	35	500	400	
2	20	68	83	83	500		
3	40	83	103	108		200	
4	10	103	108	148		400	
5	30	173	193	193	500		
Sum					1500	1000	0
item 3	demand	stj	ctj	due(hours)	scj	hcj	bcj
1	10	15	35	35	1000		
2	10	35	45	83		760	
3	20	45	65	108		1720	
4	5	133	148	148	1000	0	
5	15	148	163	193		900	
Sum					2000	3380	0

Table 7. Detailed result of JMSM

The optimal objective function value is Z_{JMSM}=12560. None of the jobs are backlogged. When the production capacity is tight as in this example, it is very difficult to schedule without backlogging the job.

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DESIGN OF CELLULAR MANUFACTURING SYSTEMS BY USING DATA MINING BASED APPROACH

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ABSTRACT. In this paper, we propose an uncertain association rule mining based algorithm for designing cellular manufacturing system with several key realistic production factors (namely, operation sequences, production volumes, transportation size, alternative process routing, cell size, the number of cells) under consideration.
Keywords: Data Mining, Uncertain Association Rule Mining, Cellular Manufacturing, Cell Formation.

INTRODUCTION

Cellular manufacturing has been one of the most successful ways that companies have used in order to cope with the challenges of today's global competitive environment. This approach has been applied in a variety of industries, such as machinery and tools, aerospace and defense, automotive, and electrical[30]. Reported benefits include reductions in setup times and costs, cycle times, work-in-process inventory levels, material handling times and costs, factory space requirements, product defect rates, and machine idle times. Among the problems of designing a cellular manufacturing system, cell formation is a central and foremost issue. The cell formation problem may be defined as: "if the number, types, and capacities of production machines, the number and types of parts to be manufactured, and the routing plans and machine standards for each part are known, which machines and their associated parts should be grouped together to form cells?"[28].

The cell formation problem was proved $\mathcal{NP}$-complete and involves complicated combinatorial optimization [12]. Therefore, it is not possible to compute

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the optimal solution for practices of interesting size in a reasonable amount of time. A natural approach for this problem is to look for approximate solutions that can be computed in polynomial time. During the past two decades, a considerable amount of methods and practical reports have been directed at this problem. Comprehensive reviews of the various methods for it are available in the literature [10, 14, 16, 20, 22, 29, 31].

Data mining is often defined as the process of extracting valid, previously known, comprehensible information from large data bases in order to improve and optimize business decisions [11]. Since it has led to the discovery of beneficial information from massive data, this practice has enjoyed popularity in recent years, with advances in both academia and industry. Indeed, most scientific disciplines are becoming data-intensive and turning to data mining as a tool [4].

However, the application of data mining to cellular manufacturing is still under utilized and infrequently used on a large scale. To the best of our knowledge, the first specialized academic literature [8] on this field did not appear until 2002. That work initially analyzed cellular manufacturing systems from the data mining perspective. In recent, Chen [6] developed an association rule mining (Apriori algorithm) based cell formation approach. However, this method is not valid for solving the problems with uncertain.

In this paper, we investigate the application of uncertain association rule mining to cell formation with operation sequences, production volumes, transportation size, alternative process routing, cell size, and the number of cells under consideration.

REAL-LIFE PRODUCTION FACTORS FOR CELL FORMATION

In the design of manufacturing cells, various real-life production factors should be taken into consideration. Recently, the factors of operation sequences, production volumes, transportation size, alternative routings, cell size, the number of cells, and unit material flow cost have been given substantial attention in the literature.

Operation sequences

The operation sequence is defined as an ordering of the machines on which the part is sequentially processed[27]. The sequence of operations in a part process routing has an important effect on material flow costs and part transportation times. An intermediate operation of a part performed in an external cell will need two intercell transfers as opposed to one transfer for either its first or last operation. Having consecutive operations in an external cell is no worse than having a single outside operation, since the material flow effort involved is the same.

Alternative process routings

In existing methods, most of them assumed that parts have only a unique process routing. However, in practical applications, it is well known that alternatives may exist in any level of a process plan. In some cases, there may be many alternative process routings for making a specific part, especially when the part is complex[19]. Based on alternative process routings, several benefits can be realized, such as allowing for a smaller number of machines, higher machine utilization, a reduced interdependence between cells, and an improved system throughput rate [13, 15]. Although alternative process routings provide some benefits in the design of manufacturing systems, but at the same time they actually increase the complexity to partition cells. Among all feasible alternate process routings, some are optimal in terms of manufacturing costs. In cellular manufacturing, one might choose such optimal routing in terms of costs in order to confine a part to a specific cell.

Production volumes

In industrial applications, the part volume differs for each part. However, in most cell formation approaches, part volumes are assumed to be the same. The reason is that these approaches are all based on 0-1 machine-part incidence matrix. This matrix, only represents the processing relationship between parts and machines. The crucial information for determining the material flow between machines, part quantity, can not be represented in the matrix. Therefore, the procedure to minimize the overall material movement cost needs to be based on a different representation.

Intercell and intracell movements

Material flow cost is incurred whenever consecutive operations of a part are performed on different machines. The intracell cost is incurred when consecutive operations of a given part are performed on different machines in the same cell. Similarly, the intercell cost is incurred when consecutive operations of a given part are performed on machines located in different cells. In general, it is normal that the unit cost of intercell movements is higher than the one of intracell movements. The sum of intercell and intracell movement costs is the most effective measure in the performance evaluation of cellular manufacturing systems since it directly affects various operational issues[9]. To actually reflect the overall material flows of parts, both intercell and intracell movements should be incorporated into the analysis of cell formation methods. However, in the literature, very few studies have considered both intercell and intracell movements simultaneously.

Number and size of cells

As pointed out in the literature[1, 32], with an increase in the number of cells formed, the total intercell movement cost increases, since it is likely that cells having physical travel of the part between them are located far apart. It is also likely that the part visits more cells, which requires additional coordinating efforts. On the other hand, as the number of cells increases, the size of the cells is in decreases, which results in a decrease in the cost and number of the intracell movements. Hence, the total intracell movement cost is expected to decrease as the number of cells increases. The reverse is also true since larger cell size involves a decrease in the number of cells, a decrease in the intercell cost but an increase in the cost per intracell movement and the number of intracellular moves as well as in coordination efforts within a cell. If we unilaterally minimize intercell movements, larger cells that have longer intracell distances will be developed, and therefore make the unit cost of intracell movements more expensive. In some extreme cases, the unit cost of intracell movements becomes higher than the one of intercell movements.

The size of cells must be defined based on space capacity, material-handling devices, initial investment, self-management cost and other production factors. The limit of cell size can prevent producing large cells while minimizing intercell movements. Once the cell size is given, to minimize the overall costs and enhance the self-managing and coordinating efficiency, clearly we should to minimize the number of cells.

In minimizing the overall cost, we need probe a balance of tradeoff between intercell and intracell movements. This is a complicated problem, which is determined by cell size, number of cells, cell layout and machine layout within cells.

PREREQUISITES AND NOTATIONS

Uncertain association rule mining

Association rule mining is one of the major forms of data mining and is perhaps the most common form of knowledge discovery in unsupervised learning systems[7]. It was originally proposed by Agrawal, Imielinski, and Swami [2], and its basic idea is to discover important and interesting associations among the data items such that the presence of some items in a transaction will imply the presence of other items in the same transaction.

Many extensions to the original association rule mining have been proposed to deal with some of the original algorithm's drawbacks. Examples include the use of the interestingness measure to prune down the number of rules[3, 17], mining the generalized association rules involving hierarchical data set[26] and generalized affinity-based association rule mining [23, 24]. Most of these extensions including the original algorithm make an assumption that the data set under consideration is precise or consistent and contain no ambiguity. In recent, high-performance distributed association rule mining[21], weighted association rule mining[5], and uncertainty association rule mining[25] have also been proposed.

Uncertain association rule mining was developed by Shyu *et al.*[25]. The significant feature of this method is that it can capture the uncertain item relationships in the datasets. This technique has been proved efficient in dealing with some problems with uncertain.

In uncertain association rule mining, two sources of uncertainty were considered: the degree of individual item importance (multiplicity) and the degree of association among the items (inter-relationship). Moreover, the Dempster-Shafer evidential reasoning theory was applied to generate the association rules with the proposed support and confidence measures under uncertainty in this technique. More mathematically, let $\mathcal{D}$ be a dataset with a set of transactions, $\mathcal{I} = \{i_1, i_2, ..., i_n\}$ a set of items. Each transaction is a subset of $\mathcal{I}$, and is assigned a transaction identifier (TID). Then,

Definition 1. *An association rule has the form of $X \Rightarrow Y$, where $X \subset \mathcal{I}$, $Y \subset \mathcal{I}$, and $X \cap Y = \phi$.*

Definition 2. *The support measure for the uncertain association rule $X \Rightarrow Y$ is*

$$sup(X \Rightarrow Y) = \sum_k SL(X, Y)$$

where $SL(X, Y)$ is the Shannon-like measure of association rule $X \Rightarrow Y$, and k is the set of all transactions in $\mathcal{D}$.

Definition 3. *The confidence measure for the uncertain association rule $X \Rightarrow Y$ is*

$$con(X \Rightarrow Y) = \sum_k \frac{SL(X, Y)}{SL(X)}$$

where the summation is over all k transactions that have an implication on the itemsets.

Notations

To state our approach a little more precisely, we firstly define a notation OCN, which will be used to incorporate the real-life factors of operation sequence, and flow times in cellular manufacturing.

Supposing an operation sequence of part p in process routing r: $m_a \rightarrow m_e \rightarrow m_c \rightarrow m_d \rightarrow m_a \rightarrow m_e$. In this operation sequence, it is clear that the flow times of $m_a \rightarrow m_e$ is 2, and $m_e \rightarrow m_c$, $m_c \rightarrow m_d$, $m_d \rightarrow m_a$ is 1 respectively. We represent this operation sequence by an order dataset

$$OD^{(p,r)} = (m_a, m_e, m_c, m_d, m_a, m_e).$$

For this order dataset, we define it's order closure as follows

$$\begin{aligned} OC^{(p,r)} = \{ & m_a, m_e, m_c, m_d, m_a, m_e, (m_a, m_e), (m_e, m_c), (m_c, m_d), (m_d, m_a), \\ & (m_a, m_e), (m_a, m_e, m_c), (m_e, m_c, m_d), (m_c, m_d, m_a), (m_d, m_a, m_e), \\ & (m_a, m_e, m_c, m_d), (m_e, m_c, m_d, m_a), (m_c, m_d, m_a, m_e), \\ & (m_a, m_e, m_c, m_d, m_a), (m_e, m_c, m_d, m_a, m_e), (m_a, m_e, m_c, m_d, m_a, m_e)\}. \end{aligned}$$

Note: in $OC^{(p,r)}$ by our definition, the order sub-datasets can be duplicate.

By $OCN^{(p,r)}_{(m_{a1},m_{a2},...,m_{ah})}$ we denote the number of order sub-dataset $(m_{a1}, m_{a2}, ..., m_{ah})$ in $OC^{(p,r)}$. In the above example, $OCN^{(p,r)}_{(m_a,m_e)} = 2$, $OCN^{(p,r)}_{(m_e,m_c)} = 1$, $OCN^{(p,r)}_{(m_c,m_a)} = 0$, and so on.

By $OCN^{(p,r)}_{\{m_{a1},m_{a2},...,m_{ah}\}}$ we denote the number of order sub-datasets in $OC^{(p,r)}$ that constructed by all elements of $\{m_{a1}, m_{a2}, ..., m_{ah}\}$. For the above example,

$$OCN^{(p,r)}_{\{m_a,m_e\}} = OCN^{(p,r)}_{(m_a,m_e)}$$

and

$$\begin{aligned} OCN^{(p,r)}_{\{m_a,m_c,m_d,m_e\}} = & OCN^{(p,r)}_{(m_a,m_e,m_c,m_d)} \\ & +OCN^{(p,r)}_{(m_e,m_c,m_d,m_a)} \\ & +OCN^{(p,r)}_{(m_c,m_d,m_a,m_e)} \\ & +OCN^{(p,r)}_{(m_a,m_e,m_c,m_d,m_a)} \\ & +OCN^{(p,r)}_{(m_e,m_c,m_d,m_a,m_e)} \\ & +OCN^{(p,r)}_{(m_a,m_e,m_c,m_d,m_a,m_e)} \end{aligned}$$

Now, we give some other notations that will be used in next as follows.

M the total number of machines to be grouped into cells
m_i the i-th machine $(i = 1, ..., M)$
P the total number of part types
p part $(p = 1, ..., P)$
R_p the total number of alternative process routings of part p
r process routing $(r = 1, ..., R_p)$
Q_p the production volume for part p
q_p the transportation size for part p
S cell size
$u_{k,h}$ the h-th itemsets of large k-itemsets
u^l_k the l^{th} selected itemset of large k-itemsets
$sup_{u^l_k}$ the support measure value of itemset u^l_k

ALGORITHM APPROACH

The uncertain association rule mining algorithm for cell formation has the following inputs and outputs.

Inputs: Take a process routing of a part as a record identifier, and the machine sets of the routing as items. There are two datasets:

1). Transaction dataset $\mathcal{D}$. This dataset incorporates production volume, transportation size.

2). Inter-relationship dataset $\mathcal{R}$. It incorporates alternative process routings, flow times, and operation sequences of parts.

These input datasets are the foundations of the algorithm. It is the key stage to construct these two datasets with respect to various real-life production factors in applying uncertain association rule mining algorithm to cellular manufacturing. We will state this technique in next.

Outputs: Machine cells, and part families.

The approach of the proposed algorithm is as follows:

Stage 1: Generate datasets $\mathcal{D}$ and $\mathcal{R}$ incorporating various realistic production factors under consideration.

The transaction dataset $\mathcal{D}$ can be constructed in the following form:

Table 1: Transaction Dataset $\mathcal{D}$

TID	Part	Routing	m_1	m_2	m_3	...	m_M
1	1	1	$d_1^{1,1}$	$d_2^{1,1}$	$d_3^{1,1}$	$d_{...}^{1,1}$	$d_M^{1,1}$
2	1	2	$d_1^{1,2}$	$d_2^{1,2}$	$d_3^{1,2}$	$d_{...}^{1,2}$	$d_M^{1,2}$
3	2	1	$d_1^{2,1}$	$d_2^{2,1}$	$d_3^{2,1}$	$d_{...}^{2,1}$	$d_M^{2,1}$
4	3	1	$d_1^{3,1}$	$d_2^{3,1}$	$d_3^{3,1}$	$d_{...}^{3,1}$	$d_M^{3,1}$
$\vdots$	$\vdots$	$\vdots$					
t	p	r	$d_1^{(p,r)}$	$d_2^{(p,r)}$	$d_3^{(p,r)}$	$d_{...}^{(p,r)}$	$d_M^{(p,r)}$

where m_1, m_2, ..., m_M denote the machine 1, machine 2, ..., machine M respectively. In the table, $d_i^{(p,r)}$ is defined as

$$d_i^{(p,r)} = \begin{cases} \frac{Q_P}{q_p} & if\ part\ p\ is\ operated\ on\ machine\ i\ in\ process\ routing\ r \\ 0 & otherwise \end{cases} \tag{1}$$

The inter-relationship dataset $\mathcal{R}$ has the following form:

Table 2: Inter-relationships Dataset $\mathcal{R}$

Itemsets	r_1	r_2	... r_R
$\{m_1\}$	$R^1_{\{m_1\}}$	$R^2_{\{m_1\}}$	... $R^R_{\{m_1\}}$
$\vdots$			
$\{m_1,m_2\}$	$R^1_{\{m_1,m_2\}}$	$R^2_{\{m_1,m_2\}}$	... $R^R_{\{m_1,m_2\}}$
$\vdots$			
$\{m_1,m_2,m_3,...,m_n\}$	$R^1_{\{m_1,m_2,m_3,...,m_n\}}$	$R^2_{\{m_1,m_2,m_3,...,m_n\}}$	... $R^R_{\{m_1,m_2,m_3,...,m_n\}}$

In the table, $R^r_{\{m_{a1},m_{a2},...,m_{ak}\}}$ is defined as

$$R^r_{\{m_{a1},m_{a2},...,m_{ak}\}} = \frac{\sum_{p=1}^{P} OCN^{(p,r)}_{\{m_{a1},m_{a2},...,m_{ak}\}}}{\sum_{p=1}^{P}\sum_{k=2}^{S}\sum_{h} OCN^{(p,r)}_{u_{k,h}}}. \tag{2}$$

Stage 2: Proceed the uncertain association rule mining algorithm to obtain the association rules among machines.

Maintaining the dataset $\mathcal{D}$ and dataset $\mathcal{R}$, proceed the uncertain association rule mining approach proposed in [25], to obtain association rules among machines. The approach of uncertain association rule mining includes the following five steps.

Step 1. Calculate the *basic probability assignments* value *bpa*:

$$bpa^{(p,r)}_{\{m_{a1},m_{a2},...,m_{ai}\}} = R^r_{\{m_{a1},m_{a2},...,m_{ai}\}} \times \min\{d^{(p,r)}_{a1}, d^{(p,r)}_{a2}, ..., d^{(p,r)}_{ai}\}. \quad (3)$$

if there exists the order sub-dataset constructed by all elements of $\{m_{a1}, m_{a2}, ..., m_{ai}\}$ in $OC^{(p,r)}$. Otherwise, we set $bpa^{(p,r)}_{\{m_{a1},m_{a2},...,m_{ai}\}} = 0$.

Step 2. Normalize the above set of *bpa*-values:

$$Bpa^{(p,r)}_{\{m_{a1},m_{a2},...,m_{ai}\}} = \frac{bpa^{(p,r)}_{\{m_{a1},m_{a2},...,m_{ai}\}}}{\sum\limits_k \sum\limits_h bpa^{(p,r)}_{u_{k,h}}}. \quad (4)$$

Step 3. Construct the set of uncertain intervals $[Bel, Pl]$:

$$Bel^{(p,r)}_w = \sum_{\mathcal{W} \supseteq w} Bpa^{(p,r)}_{\mathcal{W}} \quad (5)$$

$$Pl^{(p,r)}_w = \sum_{\mathcal{W} \cap w \neq \phi} Bpa^{(p,r)}_{\mathcal{W}} \quad (6)$$

where $w, \mathcal{W} \in \bigcup\limits_k (\bigcup\limits_h u_{k,h})$.

Step 4. Compute the Shannon-like measures SL;

$$SL^{(p,r)}_w = -\frac{1}{c} \sum_{w \subseteq \mathcal{W}} [Bel^{(p,r)}_{\mathcal{W}} \log_2 Bel^{(p,r)}_{\mathcal{W}} + Pl^{(p,r)}_{\mathcal{W}} \log_2 Pl^{(p,r)}_{\mathcal{W}}] \quad (7)$$

where $c = \sum\limits_{w \subseteq \mathcal{W}} [Bel^{(p,r)}_{\mathcal{W}} + Pl^{(p,r)}_{\mathcal{W}}]$

Step 5. Measure the support values *sup* and confidence values *con*.

$$sup_w = \sum_{(p,r)} SL^{(p,r)}_w \quad (8)$$

$$con_w = \sum_{(p,r)} \frac{SL^{(p,r)}_w}{SL^{(p,r)}_{w_1}} \quad (9)$$

where w_1 is the first item of w.

Stage 3: Design machine groups based on association rules among machines.

As pointed out in section 2, in general, the unit cost of intercell movements is higher than the one of intracell movements. Moreover, to avoid the extreme unit cost of intracell, we can restrict the upper bound of the number of machines within one cell. Hence, considering the multiple real-life production factors analyzed in above and the properties of support values of association rules, we can construct a model with objective to minimize the over-all cost as follows.

(1) Initial, set $k = S$.
(2) Select the itemsets satisfying the following model:
Maximize

$$\sum_l sup_{u_k^l} \tag{10}$$

Subject to

$$\bigcap_l u_k^l = \phi \tag{11}$$

$$(\bigcup_l u_k^l)\bigcap(\bigcup_{d=k+1}^{S}(\bigcup_l u_d^l)) = \phi \tag{12}$$

(3) Check the value of $|\bigcup_{d=S}^{k}(\bigcup_l u_d^l)|$

- if $|\bigcup_{d=S}^{k}(\bigcup_l u_d^l)| < M$, set $k = k - 1$, go (2).
- if $|\bigcup_{d=S}^{k}(\bigcup_l u_d^l)| = M$, return the all selected itemsets, end.

The solution of this model results in the assignment of machines to cells maximizing association measures of the machines in the cells. In this model, the objective function (10) serves to select k machines such that the sum of support values of selected itemsets is maximized. The sets of constraints (11) and (12) ensure that each machine is assigned to only one cell. The recurrence computation from $k = S$ guarantees that the associated machines were grouped into one cell as more as possible with respect to cell size.

However, for a cell formation problem in real world, there maybe exist many designing plans by this way. Considering the alternative process routings of each part, select a plan with the minimum over-all cost as the final machine-group plan.

Stage 4: Configure the part families based on machine groups.

Based on the machine groups designed in stage 3, dispatch part to machine cells following from some dispatching rule.

In practices, there are mainly two dispatching rules. (1) Assign each part to the cell that processes the first operation of the part. This rule is very simple, but strict optimality cannot be guaranteed. (2) Assign each part to the cell that the part has the maximum number of operations in it. This rule is effective and efficient.

COMPUTATIONAL PERFORMANCE

From the theoretical analysis perspective, the efficient that the proposed algorithm is with high speed over the original association rule mining method lies in that the repeated scanning of the database to generate the itemsets is no longer necessary since both the item multiplicity and item inter-relationships are embedded in a single *bpa*. The good quality of solution over other methods lies in the technique directly incorporating the various real-life production factors, especially the alternative process routing of parts into computation model. However, in other methods, there are no efficient ways to deal with the uncertain arising from those.

Coded in Matlab 7 and implemented on a Pentium IV-based IBM-PC, the proposed algorithm has been tested and verified for the effectiveness in designing manufacturing cells. The required number of test results(see [18]) show that the proposed algorithm is efficient either in the quality of the solutions or in the speed that gets the solutions.

To sum up, comparing with other non-data mining methods for cell formation, this algorithm shows high ability in both quality and speed for designing manufacturing cells relying on the inherent advantages of data mining techniques. Comparing with the previous data mining methods for cell formation based on original association rule mining, this algorithm efficiently resolves the uncertain difficult arising in real-world. However, it should be noted that our algorithm provides solutions that are only local optimal, as strict optimality cannot be guaranteed.

FUTURE RESEARCHES

We developed an uncertain association rule mining algorithm for cell formation incorporating various realistic production factors. In designing the algorithm, although we have taken multiple real-life production factors into consideration, it is still not valid for the whole cell formation problems. For example, to some problems with machine capacity constraint or with operation time constraint, this algorithm isn't efficient. We suggest the further extension of uncertain association rule mining to more realistic cell formation problems as a future research topic.

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A STUDY ON INFORMATON SYSTEMS AUDIT OF SCM SYSTEMS
-A RISK ASSESSMENT USING AHP-

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ABSTRACT
It is important to establish IT Governance in SCM systems. To establish IT Governance, we ensure security, efficiency and effectiveness of SCM systems. Information systems (IS) audit has a role to assess the risks for SCM systems, therefore auditors assess the adequacy of the SCM system control. In the risk assessment of SCM systems, auditors need to assess various risks such as integrity risk, confidentiality risk, availability risk, efficiency risk and effectiveness risk. It is very difficult to assess the magnitude of various risks, because we cannot assess all risks with money. Therefore, auditors need an effective method for risk assessment. But in actual audit, auditors assess risks by their experiences and intuition. We propose a risk assessment method for SCM systems audit using AHP. Moreover, we show effectiveness of this approach in the SCM systems audit. Auditors also will be able to improve the transparency of the audit process and the conclusion of their audit using AHP.

INTRODUCTION
It is important to establish IT Governance in SCM systems. To establish IT Governance in SCM, we should ensure security, efficiency and effectiveness of SCM systems. IS audit has a role to assess the risks that SCM systems have, therefore the auditors assess the adequacy of the controls of SCM systems. In the risk assessment of SCM systems, auditors need to assess various risks such as effectiveness risk, efficiency risk, security risk and investment risk.

IS audit process is consist of an audit planning, an audit preparation, an audit engagement and an audit conclusion. In the audit planning step it is important to determine audit viewpoints. Auditors have some limitations of audit resources such as the numbers of auditors, the audit schedule and the audit budget. Therefore auditors perform an audit from the viewpoint, which has higher risk.

In a real audit auditors cannot assess various kinds of risks overall. Auditors gather the information about the purpose of the information systems, the amount of investment of developing and/or acquiring application systems, the numbers of users and the numbers of PCs. Auditors compare the numerical value of the information as much as possible. But Auditors cannot assess overall risks numerically, because studies on audit engineering are not enough and auditors have no useful method to determine numerically their audit viewpoints in a real audit. Auditors determine the importance of application systems by auditors' experience and intuition. Therefore auditors cannot explain the results of risk assessment numerically

Importance of SCM Systems Audit

SCM systems consist of various application systems. If any trouble occurred in the application systems, the influence of the trouble impact will be very serious. Therefore, the controls of SCM systems are very important. The purpose of implementing SCM system is related to business objectives such as effectiveness, efficiency and a return on investment of SCM systems. A company wants not only to get some merits with an alliance by implementing SCM systems, a reinforcement of production and an improvement of customer satisfaction, but also to improve productivity and shorten delivery dates. A company keep confidentiality, availability and integrity of SCM systems. Return on investment is also an important issue. A company want to get more revenue from an investment of SCM systems.

These objectives are to gain competitive edge in the market in which the competition is keen. Therefore, achieving the business objectives is the most important for Top Management. Security is the basis to achieve business objectives. If SCM systems are not secure, the company won’t achieve the objectives of implementing SCM systems and may be bankrupt. Security is consisted of confidentiality, availability and integrity. Suppose SCM systems is not secure, unauthorized access to the system, leakages of business secret, may be occurred. System troubles also will increase and the accuracy of information may not be reliable.

The purpose of IS audit is to review effectiveness, efficiency, security and return on investment of information systems. Therefore IS audit has an important role to assure controls of SCM systems, and to make sure effectiveness, efficiency, security and return on investment of SCM systems.

Audit Process and the Viewpoints of SCM Systems Audit

Auditors perform SCM systems according to the steps given in Fig.1. In the audit planning step, auditors determine the audit viewpoints and the audit scope. There are various kinds of risks concerning the application systems. Therefore the influences on a company business are also different. Auditors assess risks of application systems overall, determine the audit viewpoints, and put the audit resources into the important viewpoints. If auditors fail to determine the audit viewpoints, they couldn’t assess an important risk of some application system for which auditors should audit. In the case that auditors fail to notice important risks, auditors should take their responsibility for the failure. Therefore a risk assessment in audit planning step is very important.

Auditors perform SCM systems audit from various viewpoints. Audit viewpoints are given in Table1. We referred *COBIT* and added some viewpoints. *COBIT* is published by ITGI (IT Governance Institute) as a tool for the IT Governance. *COBIT* also provides the audit guidelines for auditors. Auditors use COBIT as a guideline to assess the adequacy of IT Governance. There are audit resources limitations described before, auditors determine the importance of audit viewpoints, and then they put audit resources into the most important audit viewpoints. Therefore the determination of audit viewpoints is very important process in the audit process.

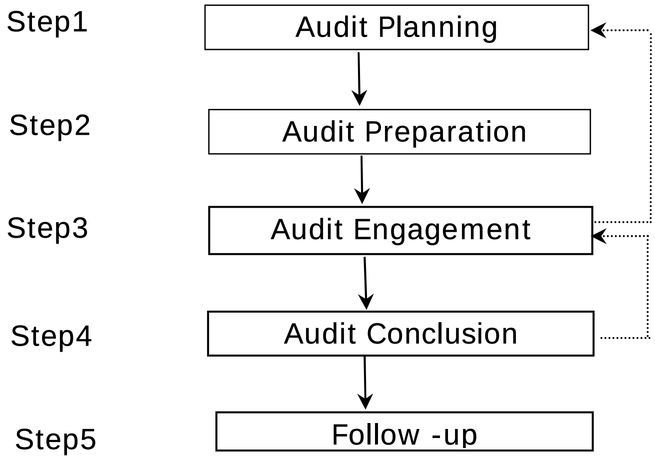

Fig.1 Process of IS auditing

Audit Viewpoints	Explanation
Effectiveness	Effectiveness deals with information being relevant and pertinent to the business process as well as being delivered in a timely, correct, consistent and usable manner. (COBIT 4.0 p.11)
Efficiency	Efficiency concerns the provision of information through the optimal (most productive and economical) use of resources. (COBIT 4.0 p.11)
Security	Security is consisted of three components: confidentiality, availability and integrity. Confidentiality concerns the protection of sensitive information from unauthorized disclosure. Availability relates to information being available when required by the business process now and future. It also concerns the safeguarding of necessary resources and associated capabilities. Integrity relate to the accuracy and completeness of information as well as to its validity in accordance with business values and expectations. (COBIT 4.0 p.11)
Investment	Return on investment. It concerns the cost benefit analysis of IT investment such as application systems development.

Table1 Audit Viewpoints

Determination of the Audit Viewpoints

To determine the audit viewpoints auditors gather information of application systems which auditors will perform an audit. For instance, they gather information such as the objectives of an application system, the amount of investment, the numbers of users and the configuration of networks. Auditors perform risk assessment for application systems from various audit viewpoints. Auditors determine the audit viewpoints based on this risk assessment. If auditors determine that security is the most important in an application system, they will audit the application system from the viewpoint of security.

Auditors determine their audit viewpoints based on the magnitude of a risk. The magnitude of a risk consists of impact and probability. If auditors determine that the impact of effectiveness is higher than the impact of security, auditors perform audit from the viewpoint of effectiveness. Auditors also consider the probability of effectiveness risk and security risk. If the probability of security risk is higher than effectiveness risk, auditors should perform an audit from the viewpoint of security. Auditors should consider both risk impact and the probability of a risk in the audit viewpoints determination.

But the determination of audit viewpoints is very difficult, because auditors must consider the impact of effectiveness, efficiency, security and return on investment. In addition to it, auditors also consider the probability of effectiveness, efficiency, security and return on investment. There are many factors to determine audit viewpoints. Auditors determine the audit viewpoints by their experience and intuition finally. Therefore it is difficult to verify and explain the appropriateness of audit viewpoint determination to other persons.

Advantages of Risk Assessment using AHP

To keep the quality and to improve the transparency, audit is getting more important. To solve these problems, we need a new approach. Auditors should perform audit from various viewpoints such as effectiveness, efficiency, security and return on investment. But auditors have limitations described before. Therefore auditors should determine a few audit viewpoints that auditors concentrate audit resources. It is not enough to assess only one kind of risk. Therefore an engineering approach is necessary to assess various kinds of risks to give the conclusion of audit.

AHP (Analytic Hierarchy Process) is one of the useful approaches to solve these problems. Auditors can assess the importance of various factors using AHP, which uses comparison of a pair of factors. Auditors compare with two factors such as the impact and the probability, effectiveness and efficiency and so on. Auditors repeat comparisons and use geometrical average. Auditors can get each importance of audit viewpoints.

By the way auditors also improve the transparency of the determination process using AHP. Auditors can also change the subjective determination of auditors to the objective one using AHP. We get some advantages described below:
①Auditors will be able to assess overall risks. Auditors will be able to determine the audit viewpoints reasonably.
②The audit process transparency and the accountability can be improved.
③Auditors get a clear ground of audit viewpoint determination. Auditors improve the quality of an audit.

Questionnaire Survey of Audit Viewpoints Determination Using AHP

We perform a survey of audit viewpoints determination using AHP. The outline of the questionnaire survey is given in Table2. The determination factor of audit viewpoints is given fig2.

Purpose of survey	Assess the probability to apply AHP to audit viewpoints determination based on risk assessment.
Object of survey	72 auditors who attended a training course held by The Institute of Internal Auditors-Japan on March 9th, 2006.
Proportion of object	Manufacturing industry: 17 auditors Service industry :24 auditors Finance business :19 auditors Other industries :12 auditors
Audit viewpoints	Effectiveness, efficiency, security and return on investment of SCM system.
Questionnaires	General questions (type of business, years of business experience) Comparison impact and probability. Comparison between effectiveness, efficiency, security and return on investment.

Table2 Outline of questionnaire survey

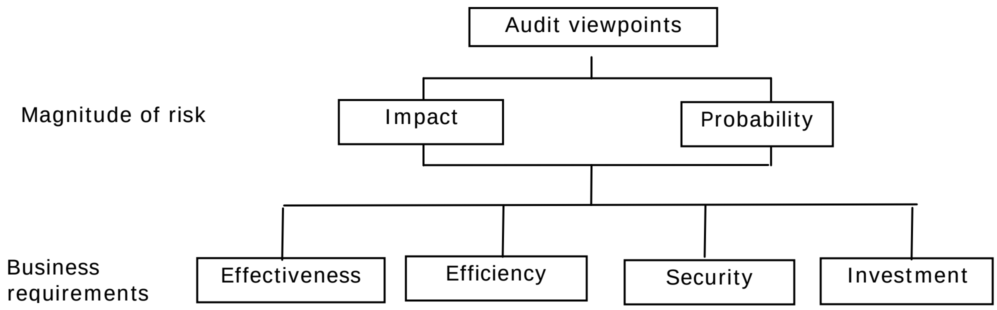

Fig.2 Determination factors of audit viewpoints

Result of Survey

The result of this survey is given in Table3-1 to Table８. Details of the result are given from Table3-1 to Table6-4. Table7 and Table8 show overall result of 72 auditors.Table3-4 shows that auditors working in the manufacturing industry determine security is the most important audit viewpoint. They determine effectiveness and return on investment are almost the same weight as audit viewpoints. Auditors working in the manufacturing industry determine that the importance of efficiency is the lowest as their audit viewpoints.

Table4-4 shows that auditors working in the service industry determine security is the most important audit viewpoint. Effectiveness is the secondly important audit viewpoint. They determine that efficiency and return on investment are not more important audit viewpoints than security and effectiveness.Table5-4 shows that auditors working in the finance business determine security is the most important audit viewpoint. Effectiveness is the secondly important audit viewpoint. They determine that the importance of return on investment is the lowest as their audit viewpoints. Auditors working in the finance business determine return on investment is not so important an issue. Table6-4 shows that auditors working in other industries determine security is the most important audit viewpoint. Return on investment is the secondly important audit viewpoint. Auditors working in other industries think that the importance of return on investment is more important than auditors working in the finance business the lowest as audit viewpoints.

Table7 shows that auditors determine security is the most important audit viewpoint. Effectiveness is the secondly important audit viewpoint. Auditors determine that efficiency and return on investment are not more important audit viewpoints than security and effectiveness. Auditors determine the importance of impact is more important than the importance of probability.Table8 also gives the differences in industries. Auditors working in the manufacturing companies and other industries determine return on investment is more important than efficiency. But Auditors working in the service industry and finance business determine that efficiency is more important than return on investment.

	Impact	Probability	Importance
Impact	1	5	0.833
Probability	1/5	1	0.167

C.I. = 0

Table3-1 Result using AHP (Manufacturing industry-impact & probability)

	Effectiveness	Efficiency	Security	Investment	Importance
Effectiveness	1	5	1/5	1	0.183
Efficiency	1/5	1	1/5	1	0.082
Security	5	5	1	5	0.612
Investment	1	1	1/5	1	0.122

C.I. = 0.11, C.R. = 0.12

Table3-2 Result using AHP (Manufacturing industry-impact)

	Effectiveness	Efficiency	Security	Investment	Importance
Effectiveness	1	1	1/5	1/5	0.082
Efficiency	1	1	1/5	1	0.122
Security	5	5	1	5	0.612
Investment	5	1	1/5	1	0.183

C.I. = 0.11, C.R. = 0.12

Table3-3 Result using AHP (Manufacturing industry-probability)

	Impact	Probability	Importance
Effectiveness	0.153	0.014	0.166
Efficiency	0.068	0.020	0.089
Security	0.510	0.102	0.612
Investment	0.102	0.031	0.133

Table3-4 Result using AHP (Manufacturing industry)

	Impact	Probability	Importance
Impact	1	5	0.833
Probability	1/5	1	0.167

C.I. = 0

Table4-1 Result using AHP (Service industry-impact & probability)

	Effectiveness	Efficiency	Security	Investment	Importance
Effectiveness	1	5	1/5	5	0.261
Efficiency	1/5	1	1/5	1	0.078
Security	5	5	1	5	0.583
Investment	1/5	1	1/5	1	0.078

C.I. = 0.11, C.R. = 0.12

Table4-2 Result using AHP (Service industry-impact)

	Effectiveness	Efficiency	Security	Investment	Importance
Effectiveness	1	1	1/5	5	0.183
Efficiency	1	1	1/5	1	0.122
Security	5	5	1	5	0.612
Investment	1/5	1	1/5	1	0.082

C.I. = 0.11, C.R. = 0.12

Table4-3 Result using AHP (Service industry-probability)

	Impact	Probability	Importance
Effectiveness	0.217	0.031	0.248
Efficiency	0.065	0.020	0.085
Security	0.486	0.102	0.588
Investment	0.065	0.014	0.079

Table4-4 Result using AHP (Service industry)

	Impact	Probability	Importance
Impact	1	5	0.8333
Probability	1/5	1	0.1667

C.I. = 0

Table5-1 Result using AHP (Finance business–impact & probability)

	Effectiveness	Efficiency	Security	Investment	Importance
Effectiveness	1	5	1/5	3	0.234
Efficiency	1/5	1	1/5	1	0.080
Security	5	5	1	5	0.595
Investment	1/3	1	1/5	1	0.090

C.I. = 0.09, C.R. = 0.10

Table5-2 Result using AHP (Finance business-impact)

	Effectiveness	Efficiency	Security	Investment	Importance
Effectiveness	1	1/5	1/5	5	0.123
Efficiency	5	1	1	5	0.411
Security	5	1	1	5	0.411
Investment	1/5	1/5	1/5	1	0.055

C.I. = 0.11, C.R. = 0.12

Table5-3 Result using AHP (Finance business-probability)

	Impact	Probability	Importance
Effectiveness	0.215	0.020	0.235
Efficiency	0.096	0.069	0.164
Security	0.480	0.069	0.548
Investment	0.043	0.009	0.052

Table5-4 Result using AHP (Finance business)

	Impact	Probability	Importance
Impact	1	3	0.750
Probability	1/3	1	0.250

C.I. = 0

Table6-1 Result using AHP (Other industries–impact & probability)

	Effectiveness	Efficiency	Security	Investment	Importance
Effectiveness	1	1	1/5	1/3	0.096
Efficiency	1	1	1/5	1/3	0.096
Security	5	5	1	3	0.558
Investment	3	3	1/3	1	0.249

C.I. = 0.01, C.R. = 0.02

Table6-2 Result using AHP (Other industries-impact)

	Effectiveness	Efficiency	Security	Investment	Importance
Effectiveness	1	3	1	1	0.323
Efficiency	1/3	1	1	1	0.186
Security	1	1	1	1	0.245
Investment	1	1	1	1	0.245

C.I. = 0.05, C.R. = 0.06

Table6-3 Result using AHP (Other industries-probability)

	Impact	Probability	Importance
Effectiveness	0.106	0.081	0.187
Efficiency	0.048	0.061	0.109
Security	0.412	0.061	0.473
Investment	0.184	0.047	0.231

Table6-4 Result using AHP (Other industries)

	Impact	Probability	Importance
Effectiveness	0.217	0.030	0.247
Efficiency	0.065	0.030	0.095
Security	0.486	0.099	0.585
Investment	0.065	0.009	0.074

Table7 Result using AHP (Total)

	Manufacturing industry	Service industry	Finance business	Other industries
Effectiveness	0.166	0.248	0.235	0.187
Efficiency	0.089	0.085	0.164	0.109
Security	0.612	0.588	0.548	0.473
Investment	0.133	0.079	0.052	0.231

Table8 Result using AHP (Differences in industries)

Conclusion

The approach using AHP in auditor's determination of audit viewpoints is a useful method in the SCM systems. Because there are some advantages as described below:

①Improve transparency of auditor's determination

It is hard to explain the process of auditor's determination by intuition and experience. But auditors can explain the process of auditor's determination using AHP. AHP can improve the transparency of auditor's determination.

②Make the auditor's determination clear

We can prove the importance of each audit viewpoints numerically. We can prove the importance of impact and probability of each audit viewpoint.

③Review the auditor's determination.

We can review the appropriateness of auditor's determination. We can review the numeric importance of the result of determination using AHP.

④Make the auditor's determination factors clear

Using AHP means that auditors can make their determination factors clear such as impact, probability, effectiveness, efficiency, security and return on investment.

Moreover we can use the questionnaire survey of auditor's determination of audit viewpoints. This survey shows that we can compare the auditor's determination using AHP. From the results of our survey, we grasped the difference among the different auditors who work at different companies. As a future subject, we will perform some survey that makes clear the auditor's determination using AHP. In addition to it, we will be able to contribute the improvement of auditors' determination, transparency of auditors' determination and the accountability of auditors.

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PERFORMANCE EVALUATION OF SCM IN JIT ENVIRONMENT

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ABSTRACT

Under stochastic demand and deterministic processing times, we discussed a single-stage JIT production system with the production-ordering and supplier Kanbans and derived a probability generating function (p.g.f.) of the stationary distributions of the backlogged demand. In this paper, we extend the system to supply chain management in JIT environment with two kinds of Kanbans under stochastic demand, deterministic processing times and withdrawals with lead time. These conditions are more realistic than the previous papers. We develop an algorithm for the exact performance evaluation of the SCM such as the stationary distributions of the inventory level, production quantities and total backlogged demand in each stage, using discrete-time Markov process. Optimal numbers of two kinds of Kanbans in the system are determined by minimizing a general total cost function. Numerical examples are given to show the efficiency of the proposed approach.

INTRODUCTION

Under stochastic demand and deterministic processing times, Ohno, *et al*. (1995) discussed a single-stage JIT production system with the production-ordering and supplier Kanbans and derived a probability generating function (p.g.f.) of the stationary distributions of the backlogged demand. In this chapter, we expand the system to a multi-stage JIT production system with two kinds of Kanbans under stochastic demand, deterministic processing times and withdrawals with lead time. These conditions are more realistic than those of Mitra and Mitrani (1990, 1991), Kirkavak and Dinçer(1996) and Berkley (1992). We develop an algorithm for the exact performance evaluation of the JIT production system such as the stationary distributions of the inventory level, production quantities and total backlogged demand in each stage, by a discrete-time Markov process. Optimal numbers of two kinds of Kanbans in the multi-stage JIT production system are determined by

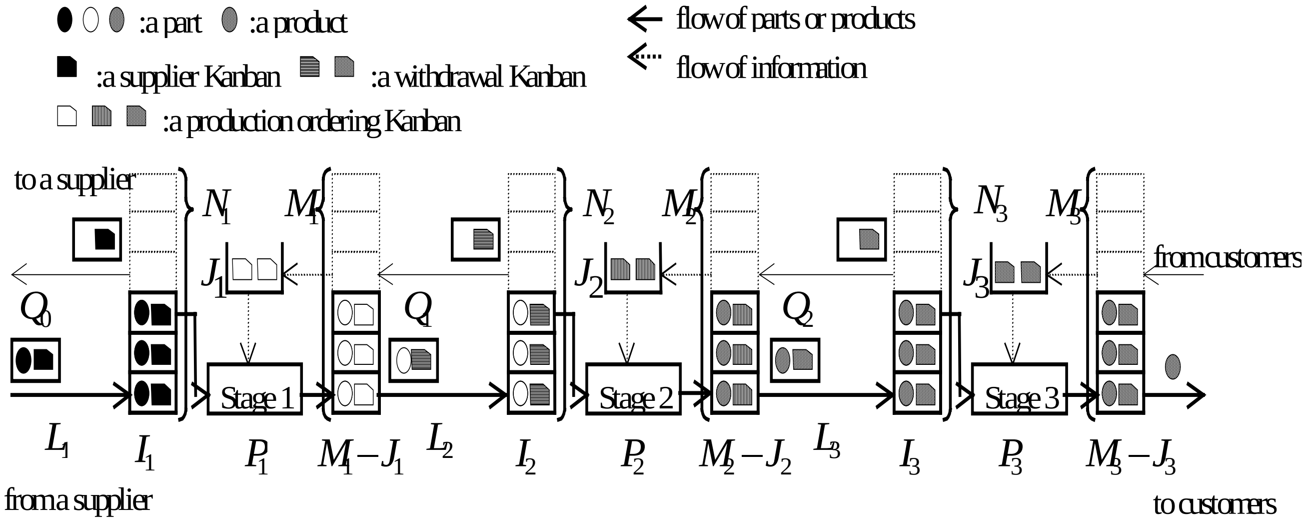

Figure 1: A multi-stage JIT production system(n=3)

minimizing a general total cost function. Numerical examples show the efficiency of the proposed algorithm.

A MULTI-STAGE JIT PRODUCTION SYSTEM

We expand the JIT production system with supplier and production-ordering Kanbans (Ohno *et al.* 1995) into a multi-stage production system, which is shown in Figure 1. The preceding stage of stage 1 is a supplier. For simplicity, take the constant delivery cycle as one period. In this system, the demand is stochastic and the processing time is deterministic. The following notation is used:

n : the number of the stage,

j : the index of the stage ($1 \le j \le n$, n is the index of the final stage),

L_j : the delivery lead time of the parts at stage j,

M_j : the number of production-ordering Kanbans at stage j,

N_j : the number of withdrawal Kanbans at stage j,

C_j : the production capacity of stage j,

$D(k)$: the demand in period k,

$B_j(k)$: the backlogged demand at stage j at the beginning of period k,

$I_j(k)$: the inventory level of the part at stage j at the beginning of period k,

$J_j(k)$: the number of the production-ordering Kanban in the production-ordering Kanban post at stage j at the beginning of period k,

$P_j(k)$: the production quantity at stage j in period k,

$Q_j(k)$: the delivery quantity of the part at stage *j* in period *k*,

$X_j(k) = B_j(k) + J_j(k)$: the total backlogged demand at stage *j* at the beginning of period *k*.

The order of parts consumed at stage *j* in period *k*= 1, 2, ⋯ is transmitted to stage (*j* – 1) at the beginning of period (*k* + 1), and they are delivered at the beginning of period (*k* + L_j + 1). It is assumed that the demand of the product in each period is independent and identically distributed with distribution {Pr{*D*(*k*)=*d*}= p_d , *d*=0,1, ⋯, D_{max}} and mean *D*, the order of the parts is instantly transmitted from stage *j* to stage (*j* – 1), the excess demands of the products or parts are backlogged at each stage and the container capacity is equal to one.

Since L_1 is the delivery lead time of the supplier, N_1 denotes the number of supplier kanbans and the number of supplier kanbans transmitted to the supplier at the beginning of periods *k* is $P_1(k\text{-}1)$, it holds that for *k*=1,2,3, ⋯

$$N_1 = I_1(k) + \sum_{i=k-L_1}^{k-1} P_1(i) \tag{1a}$$

where $P_1(0)$, $P_1(-1)$, ⋯, $P_1(-L_1+1)$ are given. Similarly, N_j, $2 \le j \le n$, withdrawal kanban s circulate between stages (*j*-1) and *j*, and

$$N_j = I_j(k) + P_j(k-1) + B_{j-1}(k) + \sum_{i=k-Lj+1}^{k-1} Q_{j-1}(i), \quad 2 \le j \le n \tag{1b}$$

where $Q_j(0)$, $Q_j(-1)$, ⋯, $Q_j(-L_{j+1}+2)$, $1 \le j \le n\text{-}1$ are given. Since the inventory level of the part at the beginning of period (*k* + 1) is changed from that of periods *k* by the difference between the delivery quantity from the preceding stage at the beginning of period *k* and the consumed quantity of the part in period *k*, it holds that

$$I_1(k+1) = I_1(k) + P_1(k-L_1) - P_1(k) \tag{2a}$$

and

$$I_j(k+1) = I_j(k) + Q_{j-1}(k-L_j+1) - P_j(k), \quad 2 \le j \le n. \tag{2b}$$

In the JIT production system, the production quantity is determined by the minimum among the inventory level of the part, the production-order quantity and the product ion capacity. That is,

$$P_j(k) = \min(I_j(k), J_j(k), C_j), \quad 1 \le j \le n. \tag{3}$$

The backlogged demand at stage *j* occurs at the beginning of period (*k* + 1) if the sum of the backlogged demand at the beginning of period *k* and the demand from the subsequent stage or customers in period k exceeds the sum of the production quantity and the inventory level of produced parts, M_j-$J_i(k)$. Therefore,

$$B_j(k+1) = [B_j(k) + J_j(k) + P_{j+1}(k-1) - P_j(k) - M_j]^+ ,\ 1 \le j \le n\text{-}1, \tag{4a}$$

and
$$B_n(k+1) = [B_n(k) + J_n(k) + D(k) - P_n(k) - M_n]^+ , \tag{4b}$$

where $[x]^+$ = max(0,x). Since the number of production-ordering kanbans at the production-ordering kanban post at the beginning of period (k + 1) is the minimum between M_j and the total backlogged demand at the beginning of period (k + 1),

$$J_j(k+1) = \min(M_j, B_j(k) + J_j(k) + P_{j+1}(k-1) - P_j(k)),\ 1 \le j \le n\text{-}1 \tag{5a}$$

and
$$J_n(k+1) = \min(M_n, B_n(k) + J_n(k) + D(k) - P_n(k)) \ . \tag{5b}$$

The delivery quantity in period k is determined by the minimum between the sum of the demand from the subsequent stage or customers in period k and the backlogged demand at the beginning of period k and the sum of the production quantity in period k and the inventory level of the product at the stage at the beginning of period k. That is,

$$Q_j(k) = \min(P_{j+1}(k-1) + B_j(k), P_j(k) + [M_j - X_j(k)]^+),\ 1 \le j \le n\text{-}1, \tag{6a}$$

and
$$Q_n(k) = \min(D(k) + B_n(k), P_n(k) + [M_n - X_n(k)]^+) \ . \tag{6b}$$

Since the total backlogged demand at the beginning of period (k + 1) is changed from that of period k by the difference between the demand from the subsequent stage or customer in period k and the production quantity at the stage in period k, it holds that

$$X_j(k+1) = X_j(k) + P_{j+1}(k-1) - P_j(k),\ 1 \le j \le n\text{-}1, \tag{7a}$$

and
$$X_n(k+1) = X_n(k) + D(k) - P_n(k) . \tag{7b}$$

THE STATIONARY DISTRIBUTION OF THE JIT PRODUCTION SYSTEM

Define the state space in period k as

$S(k) = [I_j(k), X_j(k), Q_{j-1}(i),\ 1 \le j \le n,\ k - L_j + 1 \le i \le k-1]$,

where $Q_0(i) = P_1(i-1)$. Let $i_j(k), x_j(k)$ and $q_{j-1}(i)$ ($1 \le j \le n$, k-L_j+1$\le i \le k$-1) denote realizations of the corresponding random variables $I_j(k), X_j(k)$ and $Q_{j-1}(i)$, respectively. Since $D(k)$, k = 1,2,3, ⋯, are independent and identically distributed, and $[I_j(k), X_j(k), Q_{j-1}(i)$, $1 \le j \le n$, $k-L_j+1 \le i \le k-1]$ determines all states of the JIT production system by equations (1) through (7), $S(k)$ is a Markov chain with the following transition probabilities:

$\Pr\{S(k+1) = s(k+1) \mid S(k) = s(k)\}$,

$= \Pr\{D(k) = d\} = p_d$,

$$\textit{if}\ \ i_j(k+1) = i_j(k) + q_{j-1}(k - L_j + 1) - \min\{i_j(k),\ x_j(k),\ M_j,\ C_j\} \quad ,1 \le j \le n,$$

$$\begin{aligned} x_j(k+1) = x_j(k) + N_{j+1} - i_{j+1}(k) - \sum_{i=k-L_{j+1}+1}^{k-1} q_j(i) - [x_j(k) - M_j]^+ \\ - \min\{i_j(k),\ x_j(k),\ M_j,\ C_j\} \end{aligned} \quad ,1 \le j \le n-1,$$

$$x_n(k+1) = x_n(k) + d - \min\{i_n(k),\ x_n(k),\ M_n,\ C_n\}$$

$$\begin{aligned} q_j(k) = \min\{N_{j+1} - i_{j+1}(k) - \sum_{i=k-L_{j+1}+1}^{k-1} q_j(i), \\ \min\{i_j(k),\ x_j(k),\ M_j,\ C_j\} + [M_j - x_j(k)]^+\} \end{aligned} \quad ,1 \le j \le n-1,$$

$$q_0(k) = N_1 - i_1(k) - \sum_{i=k-L_1+1}^{k-1} q_0(i) \quad ,$$

$$i_j(k) + \sum_{i=k-L_j+1}^{k-1} q_{j-1}(i) \le N_j,\ \ 1 \le j \le n, \tag{8}$$

=0, *otherwise*.

Under stability condition (Ohno *et al.* 1995), for $1 \le j \le n$, $k-L_j+1 \le i \le k-1$ and integers i_j, x_j, $q_{j-1,i}$, the limiting probabilities $\Pr\{I_j(\infty) = i_j,\ X_j(\infty) = x_j,\ Q_{j-1,i}(\infty) = q_{j-1,i},\ 1 \le j \le n,\ 1-L_j \le i \le -1\} = \lim_{k\to\infty} \Pr\{I_j(k) = i_j,\ X_j(k) = x_j,\ Q_{j-1}(i) = q_{j-1,i},\ 1 \le j \le n,\ k-L_j+1 \le i \le k-1\}$ exist. Denote by $\boldsymbol{\pi}$ the limiting distribution. That is, $\boldsymbol{\pi} = (\Pr\{I_j(\infty) = i_j,\ X_j(\infty) = x_j,\ Q_{j-1,i}(\infty) = q_{j-1,i},\ 0 \le i_j \le N_j,\ 0 \le x_j \le M_j + N_{j+1},\ 0 \le q_{j-1,i} \le N_j,\ 1 \le j \le n,\ 1-L_j \le i \le -1\})$. Then $\boldsymbol{\pi}$ can be obtained by solving the following balance equations of the Markov chain:

$$\boldsymbol{\pi M} = \boldsymbol{\pi} \text{ and } \boldsymbol{\pi e}^T = 1, \tag{9}$$

where $\boldsymbol{e}$ is a row vector with all elements equal to one and $\boldsymbol{M}$ is the transition probability matrix.

AN ALGORITHM FOR THE EXACT PERFORMANCE EVALUATION

We consider the total backlogged demand, inventory level and production quantities as performance measures in the JIT production system and devised an algorithm for the exact performance evaluation of the system as follows:

Step 1.

For L_j, M_j, N_j and C_j ($1 \le j \le n$), define the state space S(k) and calculate the transition probability matrix $\boldsymbol{M}$ by equation (8).

Step 2.

Compute the limiting distribution $\boldsymbol{\pi}$ of S by solving the balance equations (9).

Step 3.

Compute the limiting distribution of the total backlogged demand $\{\Pr\{X_j(\infty)=x_j\}\}$ and that of inventory levels $\{\Pr\{I_j(\infty)=i_j\}\}$ from $\boldsymbol{\pi}$ = ($\Pr\{I_j(\infty)= i_j$, $X_j(\infty)= x_j$, $Q_{j-1,i}(\infty)= q_{j-1,i}$, $1\le j \le n$, $1-L_j \le i \le -1\}$), and the limiting distribution of production quantity $\{\Pr\{P_j(\infty)=p_j\}\}$ by equations (3), (5), (7) and $\boldsymbol{\pi}$.

OPTIMIZATION OF THE NUMBERS OF KANBANS

The JIT production system adapts to variable demands at a small cost by production smoothing (Monden 1998). Through production smoothing, the stages can reduce idle time or overtime costs of workers or machines. We call these costs related to production quantities <u>production fluctuation costs</u> and include them in a cost function of the JIT production system.

Suppose that the ordered quantities, $Q_j(0)$, $\cdots$, $Q_j(-L_{j+1}+2)$, $0 \le j \le n-1$ are given. Then, a standard cost function over K periods is as follows:

$$
\begin{aligned}
&A(M_j, N_j, 1\le j \le n, K) \\
&= E[\sum_{j=1}^{n}\{\sum_{k=1}^{K}\{A_{I_j}(I_j(k)-P_j(k)/2)+B_{I_j}(M_j-J_j(k))+A_{B_j}B_j(k) \\
&\quad + A_{O_j}P_j(k-1)+A_{W_j}Q_{j-1}(k-L_j)+\sum_{i=0}^{\min(M_j,C_j)}A_{P_j}(i)\Pr\{P_j(k)=i\}+C_{B_j}I\{B_j(k)>0\} \\
&\quad + C_{OW_j}(M_j,N_j)\} \quad + A_{S_j}(I_j(K)-P_j(K))+\sum_{i=1}^{L_j}A_{E_j}(i)P_j(K-i)\}], \qquad (10)
\end{aligned}
$$

where $I\{H\}$ is the indicator function of event H, that is, $I\{H\}=1$ if H occurs;=0, otherwise. In addition,

A_{I_j} : the inventory cost of one part in stage *j* per period,

B_{I_j} : the inventory cost of one product in stage *j* per period,

A_{B_j} : the backlogged cost of one product in stage *j* per period,

A_{O_j} : the ordering cost of one part in stage *j*,

A_{W_j} : the withdrawing cost of one part in stage *j*,

$A_{P_j}(i)$: the production fluctuation cost per period when the production quantity at stage *j* is *i*.

C_{B_j} : the backlogged cost at stage *j* per once,

A_{S_j} : the salvage cost of one part in stage *j* at the end of period *K*,

$A_{E_j}(i)$: the salvage cost of one part in stage *j* elapsed *i* periods after the ordering at the end of period *K*,

and

$C_{OW_j}(M_j, N_j)$: the fixed cost per period of storage space at stage *j*, ordering and withdrawing when the numbers of Kanbans are M_j and N_j.

We consider the average cost per periods over an infinite planning horizon in this research. The average costs per period, $A(M_j, N_j, 1 \le j \le n)$ is defined by

$$A(M_j, N_j, 1 \le j \le n) \quad = \limsup_{K \to \infty} A(M_j, N_j, 1 \le j \le n, K)/K. \tag{11}$$

Under the stability condition, distributions of $B_j(k)$, $I_j(k)$, and $J_j(k)$ also converge to their own stationary distributions, as *k* tends to infinity, and denote by $B_j(\infty)$, $I_j(\infty)$, and $J_j(\infty)$ random variables with the stationary distributions. Then it follows from (10) and (11) that

$$A(M_j, N_j, 1 \le j \le n)$$
$$= \sum_{j=1}^{n} \{A_{I_j}(E[I_j(\infty)] - E[P_j(\infty)]/2) + B_{I_j}(M_j - E[J_j(\infty)]) + A_{B_j} E[B_j(\infty)]$$
$$+ (A_{O_j} + A_{W_j}) E[P_j(\infty)] + \sum_{i=0}^{\min(M_j, C_j)} A_{P_j}(i) \Pr\{P_j(\infty) = i\} + C_{Bj} \Pr\{B_j(\infty) > 0\} + C_{OW_j}(M_j, N_j)\} \tag{12}$$

Thus, if we obtain the stationary distributions and expectations of random variables in (12) by the algorithm devised in Section previews section, we can calculate the value of (12) and can determine optimal numbers of Kanbans, M_j^* and N_j^* (1 ≤ *j* ≤ *n*) that minimize $A(N_j, M_j, 1 \le j \le n)$.

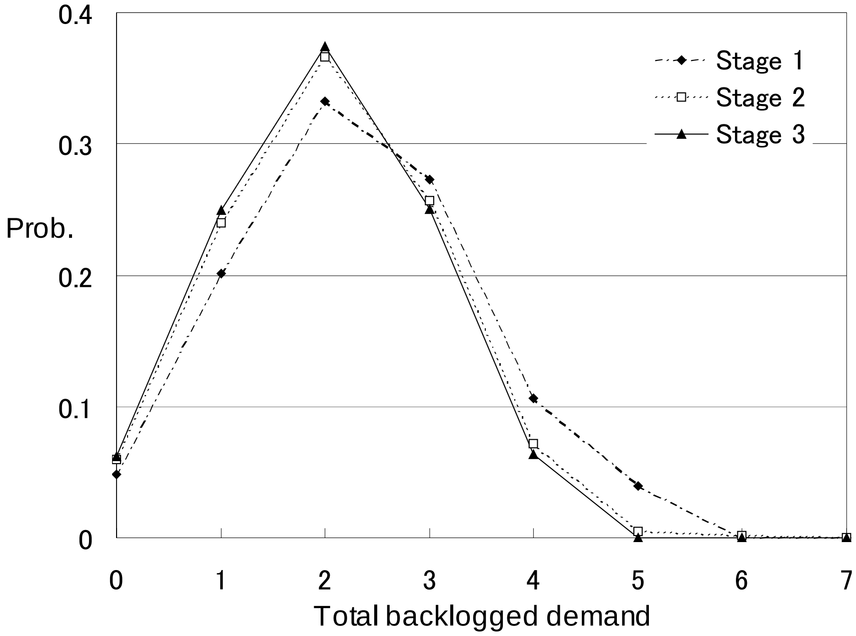

Figure2: Probability distributions of the total backlogged demand for (M_1, M_2, M_3) = (4,4,4) and (N_1, N_2, N_3) = (5,6,7)

NUMERICAL EXAMPLES

The algorithm devised in The previews section is applied to the 3-stage JIT production system with the average demand D = 2, the lead time (L_1, L_2, L_3) = (1,1,1) and the production capacity (C_1, C_2, C_3) = (4,4,4). The distribution of the demand $D(k)$, k = 1,2,3,⋯ is a binomial distribution with mean D. The truncated backlogged demand level is 10.

Figure 3.2 shows the distributions of the total backlogged demand at each stage with (M_1, M_2, M_3) = (4,4,4) and (N_1, N_2, N_3) = (5,6,7).

The cost parameters in (3.12) are set as follows:

$(A_{I_1}, A_{I_2}, A_{I_3})$ = (1,3,5), $(B_{I_1}, B_{I_2}, B_{I_3})$ = (3,5,10), $(A_{B_1}, A_{B_2}, A_{B_3})$ = (0,0,0),

$(A_{O_1} + A_{W_1},\ A_{O_2} + A_{W_2},\ A_{O_3} + A_{W_3})$ = (1,2,3), $(C_{B_1}, C_{B_2}, C_{B_3})$ = (0,0,1000),

$(C_{OW_1}(M_1, N_1), C_{OW_2}(M_2, N_2), C_{OW_3}(M_3, N_3))$ = (0,0,0)

and $A_{P_j}(i) = \begin{cases} 50(i-3) & 4 \le i \\ 0 & 0 \le i \le 3 \end{cases}$, j=1,2,3.

Then the optimal numbers of production-ordering Kanbans and withdrawal Kanbans are (M_1^*, M_2^*, M_3^*)= (3,3,4) and (N_1^*, N_2^*, N_3^*)= (5,6,6), respectively.

CONCLUSION

In this chapter, we deal with a multi-stage JIT production system with two kinds of Kanbans. Under the stochastic demand and deterministic processing times and withdrawals with lead time, an algorithm for the exact performance of the JIT production system is devised based on the Markov process. We can compute optimal numbers of two kinds of Kanbans by using the algorithm. Numerical results show the exact performance of the multi-stage JIT production system and the optimal numbers of two kinds of Kanbans.

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THE SELECTION OF FACILITIES UNDER COMPETITIVE ENVIRONMENT

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ABSTRACT

One of objectives in the supply chain management is to cut down expenses by composing a network of the distribution system on production activities. When we usually compose a serial distribution system, we will choose a production/distribution facility out of business firms affiliated with the same group. However, if we aim at an improvement in efficiency, we should consider not only the firms affiliated with the same group but also many independent production/distribution facilities as an object. This assumption causes competition in a selection of facilities composing a serial supply chain. In this paper, we deal with a selection problem to compose a serial supply chain from many production/distribution facilities under competitive environment. We give a mathematical formulation to this problem with two supply chains and analyze it from a view point of the game theoretical consideration.

INTRODUCTION

Supply chain management is to take an alert correspondence to the whole supply chain under uncertain demands and to optimize it dynamically. Although various criteria are used on the optimization of inventory control problems, a major criterion is probably to minimize total costs in the whole of a supply chain system or to maximize gross profit with production activities. The formulation is given by a constrained non-linear programming problem, a multiple-criteria decision making problem and so on. In this paper, to simplify our argument, we discuss on the previous formulation.

In a mathematical programming formulation, we consider cutting down expenses by composing a network of the distribution system on production activities as one of objectives in the supply chain management. There are various constraint conditions with objective function in a serial of production activities. For instance, the reduction of lead time, the reduction of processing stocks, a rise in reliability of products, a rise in a name value of company, risk from excess and being out of stock with respect to resources required in production process, and so on. If the number of constrained conditions increases in a mathematical programming problem, the number of feasible solutions decreases. If many conditions are given for a problem, it is even possible that there exists no feasible solution. When such a situation happens, we need reconsider on a mathematical problem which is loosen constrained conditions again. This is caused by harsh conditions.

If the decision maker is just particular about minimizing of total costs, it may occur a lowering of quality or give the longer lead time. On production activities, the constrained conditions usually conflict the direction for the objective function. Although the published researches often treated problems on supply chain management as mathematical optimizing problems, we will be able to offer a flexible procedure by turning attention to not only the objective function but also the constrained conditions. In this paper we suggest a selection procedure to compose a serial supply chain from many production/distribution facilities under competitive environment.

NOTATION AND ASSUMPTIONS

We suggest how to select appropriate facilities in order to compose a serial supply chain from some production/distribution facilities under competitive environment. Now, we suppose that there are two competing companies, called Player 1 and Player 2, and they consider choosing n appropriate facilities from some production/distribution facilities. This may be regarded as a machine selection problem on the stage of production activities in the narrow sense, and as a problem such that a large corporation selects a serial of route with relation to suppliers, manufacturers, distributors and retailers in the broad sense. Let $m_1^i, m_2^i, \ldots, m_{k_i}^i$ denote k_i possible facilities to choose in the stage $i\,(i=1,2,\ldots,n)$, and let M_i denote set composed by them. That is, $M_i = \{m_1^i, m_2^i, \ldots, m_{k_i}^i\}$. Putting $k = k_1 k_2 \cdots k_n$, both players have k strategies composed by choosing one of elements from set M_i for each i. Then, players select a strategy $(m_{j_1}^1, m_{j_2}^2, \ldots, m_{j_n}^n)$ $\in M_1 \times M_2 \times \cdots \times M_n$ under a certain criterion. When players choose one of k feasible strategies, the serial of supply chain system is decided.

PROCEDURE

Let $\mathbf{x} = (x_1, x_2, \ldots, x_n)$ and $\mathbf{y} = (y_1, y_2, \ldots, y_n)$ denote the strategies for Players 1 and 2, which are in $M_1 \times M_2 \times \cdots \times M_n$, respectively. The usual problem will be formulated as mathematical programming problem of the form

$$\begin{aligned} & f(\mathbf{x}) \to \max \\ s.t.\quad & g^i(\mathbf{x}) \le b_i \quad (i = 1, 2, \ldots, i_0) \\ & g^i(\mathbf{x}) \ge b_i \quad (i = i_0, i_0+1, \ldots, i_1) \end{aligned}$$

for each player, where $f(\mathbf{x})$ is the objective function, $g^i(\mathbf{x})$ are the constraint functions, and i_1 is the number of considerable constrained conditions. For example, the objective function $f(\mathbf{x})$ is given as profit per unit and the constraint functions $g^i(\mathbf{x})$ may represent lead time or reliability. On constrained conditions, if anything, $g^i(\mathbf{x}) \ge b_i$ implies $g^i(\mathbf{x}) \to \min$ and $g^i(\mathbf{x}) \le b_i$ implies $g^i(\mathbf{x}) \to \max$ in consideration of mean of the objective function $f(\mathbf{x})$. To hold a course similar to the objective function, the former replaces $g^i(\mathbf{x}) \to \min$ with $-g^i(\mathbf{x}) \to \max$ by multiplying -1.

Now, let $f_1^i(\mathbf{x})$ denote the value of criterion when Player 1 uses the strategy $\mathbf{x} \in M_1 \times M_2 \times \cdots \times M_n$. These are given by the objective function and the constraint functions. We define a vector value $(f_1^1, f_1^2, \ldots, f_1^{i_1+1})$ arranged by the order in which Player 1 desires as the strategy for Player 1. Similarly, letting $f_2^i(\mathbf{y})$ denote the criterion value when Player 2 uses the strategy $\mathbf{y} \in M_1 \times M_2 \times \cdots \times M_n$, a vector value $(f_2^1, f_2^2, \ldots, f_2^{i_1+1})$ represents the strategy for Player 2. In each stage of supply chain, if there is no connection between companies or if only one player may utilize it when two players choose same company in some stage, we define that the value of component of vector is equal to $-\infty$.

We merely do not consider the optimizing problem, but game-theoretically analyze our problem by using these vector values, which treat the constrained conditions as objective functions. We make one bimatrix by arranging the corresponding vector values for all pairs of strategies $(\mathbf{x}, \mathbf{y})$ mentioned above, we find an equilibrium point for the bimatrix game under maximal criteria. We use dictionary style ordering on vector values.

CONCLUDING REMARKS

We took constrained conditions in criteria equivalent to the objective function and suggested one procedure to select appropriate facilities in order to compose a serial supply chain from many production/distribution facilities. Although the equilibrium point is not optimal solution, it will help him to get the better solution even if decision maker changes criteria, because it takes enough account of constrained conditions.

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Relationship between Business Definition and the Corporate Growth: Case Studies of Japanese Electric/Electronics Companies

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ABSTRACT

In our previous research[1], we tried to statistically investigate the relationship between business definitions and the corporate growth with 50 Japanese electric/electronics companies[2] in order to prove Theodore Levitt's hypothesis that companies could survive and grow continuously by 'function' (customer value) oriented business definitions. We got the result that there is positive correlation between 'functionality' (or magnitude that function is contained) in the business definitions and growth rate of consolidated net sales. In our current research, we test the hypothesis that in case that the functions in mission-level business definition of the whole company and those in strategy-level definition of each business unit are aligned, it will ultimately bring continuous growth to the company, based on comparative case studies of selected companies with highly functional corporate business definitions. As a result, we recognize that the one that successfully aligns divisional business definitions to its corporate business definition in terms of function continuously grows at a higher rate than the other that fails the alignment, through business processes and products/services, even among companies with similarly high functionality in the corporate business definitions.

[1] Wakabayashi (2005)

[2] 50 electric/electronics companies with largest (from the top to 50th) sales volume in FY 2003 excluding NEC Electronics founded in 2002, since it has no financial data before 2002. All the companies list their stocks in the industrial category of 'Electric Appliances' on the Tokyo Stock Exchange.

INTRODUCTION

Levitt (1960) argued that organizations stop their growth because they define their business too narrowly. Railroads companies in the US stopped growing because they assumed themselves to be in ‘railroad business’ rather than in ‘transportation business’. It happened not because the need for passenger and freight transportation declined, but they were product-oriented rather than customer-oriented. Levitt indicated that business should be defined in terms of ‘customer value’, not ‘products’ to survive and grow continuously. In other words, companies could continue growth by redefining their businesses in terms of customer value. We use the term ‘function’ as a synonym of customer value, following Hofer and Schendel (1978) who called Levitt’s ‘customer value oriented’ as ‘functional’ throughout this paper.

In our preceding research, we tried to statistically prove Levitt’s hypothesis that companies could survive and grow continuously by functional business definitions, using ‘functionality scores’ for corporate business definitions evaluated by the panel formed with 29 business people and performance data of 50 companies in Japanese electric/electronics industry.

We hired security reports (Yukashouken-houkokusho) and annual reports as the source of business definitions.

We chose electric/electronics industry for the following reasons. As the business environment of the industry is rapidly changing to keep up with the development of information technology, the difference in performance that business definitions bring to the companies is greater than for firms in other industries. Also, as it is one of the major industries of Japanese economy, various types of company are competing in diverse market segments.

We took seven years as the research duration, based on the following premises,

1. Business definitions are revised in accordance with top management’s turnovers and the average tenure of top management (CEO, or president) of Japanese companies is seven to eight years.
2. Business definitions that appear in the sources are elements of long-rage plans or corporate missions, and the target term for long–range plans is usually more than five years.

We analyzed how the business definition at the point of 1998 (FY1997) influences performance indicators of the years through 2004 (FY2003).

As a result, we found that there is a positive correlation between functionality (magnitude that function is contained) in the corporate business definitions and growth rates in consolidated net sales and market value. However, the correlation coefficients were not large enough to fully explain the causal relationship between the functionality and growth rate. Some of the results are depicted in Table 1 and 2.

The possible reason for this is that even the corporate business definition in the mission or long–range plan of the whole company is functional, if the one in the strategy of each business unit is not functional enough, the function will not be realized at the business processes such as developing products and selling them to customers, as a result, the growth rate will be lower.

In this paper, we try to empirically prove the hypothetical causal relationship that function in the corporate business definition is transferred to business units and down to products/services, ultimately it brings continuous growth to the company, focusing on the functional alignment of business definitions in various levels.

Table 1. Correlation coefficients between functionality scores and performance indicators of 50 Japanese electric/electronics companies

	Net Sales Growth Rate (FY97-03)	Net Sales Growth Rate (FY98-03)	Average Opt.Profit Rate (FY97-03)	Average Opt.Profit Rate (FY98-03)	Change in Opt.Profit Rate (FY97-03)	Change in Opt. Profit Rate (FY98-03)	Market Value (FY97)	Market Value (FY03)	Market Value Growth Rate (FY97-02)	Market Value Growth Rate (FY97-03)
Coefficients	.393***	.384***	.024	.027	-.025	-.096	-.090	.004	.338**	.330**

Notes: Net Sales Growth Rate (%) is consolidated annual rate base. Average Opt. Profit Rate (%) denotes the mean of consolidated operating profit/net sales in the term. Change in Opt. Profit Rate (FY97-03) (%) is obtained by consolidated operating profit rate in 2003 minus that in 1997. Market Value (million yen) is obtained from average stock price multiplied by the number of total stocks issued. Market Value Growth Rate (%) is annual rate base.
*** denotes significance level $p<.01$ and ** denotes $p<.05$.
Data sources: Wakabayashi(2005), etc.

Table 2. Average growth rates of consolidated net sales and test results

	FY1997-2003		FY1998-2003	
Sub-groups (N)	Mean (%)	t statistic	Mean (%)	t statistic
High (10)	9.297	2.354**	10.761	2.166**
Low (10)	-2.311		-2.247	
High (20)	5.850	2.622**	7.560	2.641**
Low (20)	-1.064		-0.652	
Total (50)	2.772		4.032	

Notes: The High (10) denotes the group of 10 companies receiving the highest functionality scores from the top and the Low (10) is that of 10 companies receiving lowest functionality scores from the bottom. The High (20) and the Low (20) are ditto.
** denotes significance level $p<.05$.
Data source: Wakabayashi(2005).

Drucker (1974) mentioned, 'The innovation objective is the objective through which a company makes operational its definition of *what our company should be*'. He also mentioned that 'innovation is not science or technology, but value'. Referring to Drucker's argument, we assume the following mechanism underlying the relationship among business definition, functional alignment, and corporate growth, as depicted in Figure 1. In the company where common function is shared by the whole organization, synchronizations around the function among employees arise, innovation happens in each business process, and that makes the company provide customers with clearer function (or customer value) through its products and services, finally it brings continuous growth to the company.

RELATED RESEARCHES AND LITERATURES

Abell (1980) proposed 'customer groups', 'customer functions', and 'alternative technologies', as the three axes to define the business. He analyzed the causal relationship of business definition and market share as the performance indicator through the case studies of the competitors in computer, ATM, CT scanners, and forestry skidders industries. However, his study is aimed at proving the efficiency of his three axes framework rather than investigating the causal mechanism of the business definition and performance.

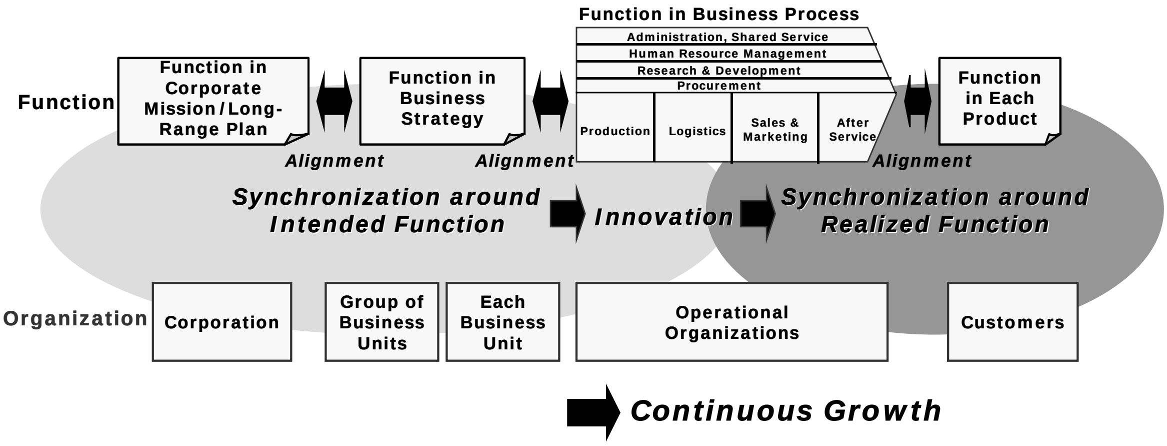

Figure 1. Hypothetical mechanism of functional alignment and growth

Sakakibara, et al (1989) studied the new business development processes at 3M, IBM, Xerox, NEC, etc. They analyzed the mechanism that business definitions in the corporate missions influence the product concepts through the new business development process. However, the study is based on the premise that corporate business definition defuses throughout the whole company, and the case that there might be misalignment between the corporate and divisional business definitions is not considered.

Sakakibara (1992) hypothetically suggests the causal mechanism that the corporate business definition influences the performance through the consensus and synchronization on it between top management and employees, also between the company and society. However, there is no consideration on the definitions on various levels from corporate mission to products/services.

Kaplan and Norton (2001) argue that strategy implementation requires that all business units, and employees be aligned and linked to the strategy. They advocate the strategy cascading from the top to the bottom of organization as the framework to realize the alignment through financial, customer, internal business process, and learning and growth perspectives. However, they do not propose any clear and indispensable axis (or base) to align the whole organization.

In order to construct the really applicable theory related to business definition, it is necessary to deal with the linkage among corporate mission, business strategies, and products/services for customers. In this sense, the predecessor studies are not enough to respond to the needs in real businesses.

RESEARCH METHODOLOGY

We propose the following as the first hypothesis in this paper,

H1: among the companies with highly functional corporate business definitions, the ones that successfully align their corporate business definitions and divisional business definitions in terms of function continuously grow at a higher rate than the others that fail the alignment.

We expand the first hypothesis to business processes and products/services and get the second hypothesis as follows,

H2: among the companies with highly functional corporate business definitions, the ones that the common function is realized in the corporate and divisional definitions continuously grow at a higher rate than those that it is not fully

realized, through superior business processes and successful products/services[3].
'Corporate business definition' is usually the one that is defined in mission statement or long-range plan for the whole company. We use 'corporation' as a synonym of the 'whole company'.
'Divisional business definition' is the one that is defined in business strategy for each business unit or group of several business units.
As the general organizational structure of Japanese companies is slightly different from the counterpart of the Western companies in terms of financial autonomy of each division, hierarchical layers, etc., the elements of the two organization charts may not completely correspond each other. In this paper, we use the term 'business unit' for product division ('Jigyoubu') of Japanese companies and 'group of business units' for intermediate layer of management between corporation and the business unit such as 'in-house company', product group ('Jigyouhonbu'), product sector, and strategic business unit, referring to the notations used in Prahalad and Bettis (1986), Watson and Wooldridge (2005), etc.
The entire procedure taken in our research is as follows,
STEP1. First, we pick up 10 companies with highest functionality scores from 50 electric/electronics companies that we analyzed in our preceding research. Asking those 10 companies for co-operation to the interview survey, we select four companies with which our requests are accepted. The profiles of those companies are as follows,
A Corporation: A precision instrument manufacturer founded in 1961. The major products include printers, LCD (liquid crystal display) projectors, LCD monitors, LCD modules, LCD drivers, watch movements, etc.
B Corporation: An office automation equipment manufacturer founded in 1936. The major products include copiers, facsimiles, fax-copiers, printers, scanners, digital cameras, CD drivers, etc.
C Corporation: An audio video equipment manufacturer founded in 1947. The major products include DVD recorders, PDPs (plasma display panels), car audios, car navigation systems, etc.
D Corporation: An electronics and entertainment conglomerate founded in 1946. The major products include camcorders, digital cameras, LCD televisions, DVD recorders, personal computers, audio equipment, home game equipment, car navigation systems, etc.
STEP2. For those four companies, security reports, annual reports, articles in newspapers[4] and business magazines[5] issued during FY 1997 through FY 2003 are gathered. The other publications such as case studies and books are also searched. From those sources, descriptions related to business definitions in various levels, business processes, and products/services are picked up, and the relationships among them are identified. Market share data of major products produced by the four companies is also collected.
STEP3. Interviews with the employees of four companies are undertaken. Interviewees are the employees who dealt with corporate planning or business strategies in FY1998. The interview questions include,

[3] There are some similarities between the framework underlying this hypothesis and the one for Balanced Scorecard. The *functional alignment* corresponds to *customer perspective*, *business processes and products/services* correspond to *internal business process perspective*, and *growth rate* corresponds to *financial perspective*.
[4] Nihonkeizai-shinbun, Nikkei-sangyo-shinbun
[5] Nikkei Business, Weekly Diamond, Weekly Toyokeizai, etc.

1. Frequency of defining the corporate business definition,
2. Influences of the business definitions over the organizations,
3. Duration that the corporate business definition in 1998 has been effective,
4. The element by that business definitions are defined (customers, functions, technologies, products, etc.),
5. Whether the corporate business definition were cascaded to business units/groups of business units,
6. If so, the expressions of the divisional business definitions,
7. The person(s) who made the corporate business definition that existed in 1998,
8. The major products that successfully went on the market under the (divisional) business definitions,

STEP4. The case studies are undertaken based on the interview survey and various published data. Then the results combined with functionality scores and growth rates are analyzed all together, based on the hypothetical framework that the functional alignment influences business processes and products/services, and ultimately the growth rate of the company, in order to prove H1 and H2. Whether the residual of the growth rate that the functionality score leaves unexplainable can be explained by the magnitude of functional alignment between corporate business definition and divisional definitions is tested.

RESULTS

The case studies of the four companies[6] are presented to reveal the magnitude of functional alignment of corporate and divisional business definitions and its influence on the corporate performance through business processes and products/services (c.f. Table 3).

Case 1: A Corporation

Corporate and divisional business definitions From July 1992 to June 1993, after the change of the company president, middle managers summoned across the divisions got the mission to set the business definitions. As a result, the following four business definitions were drown based on Abell's three axes frame; 'Saving technology' (customers: electronics and watch manufacturers, functions: supporting energy saving and space saving, technologies: consulting skills and knowledge on various energy saving technologies), 'Technical linkage' (customers: electronics manufacturers, functions: security and reliance, technologies: various energy saving technologies such as micro-precision processing, energy conserving, and high-density assembly technologies), 'Advanced standard' (customers: consumers, function: reliance, technologies: capability to forecast the future de facto standards on information technologies and interfacing technologies), and 'Comfort creation' (customers: consumers, functions: security and health, technology: sensing). Later, they were revised to 'Saving technology', 'Color imaging', 'Advanced standard', 'MicroArtist', and 'Solution provider'. The corporate business definition, 'Saving technology: to solve the customer's problem by integrating *fineness* and *energy saving*', was made up from those five business definitions as an element of the long-range plan in 1995.

In the long-range plan of January 2003, under the corporate business definition

[6] To keep each company's secrecy and each interviewee's anonymity, a pseudonymous name is used for each case company.

of ‘Digital image innovation: targeting the convergence of imaging domains’, ‘Imaging on paper’, ‘Imaging on screen’, and ‘Imaging on glass’ were developed as subordinate business definitions. Promoted by the top management, each business unit was motivated to adopt the corporate business definition to its own definition to accomplish the corporate objectives.

Outcomes in business processes and products The corporate business definition had positively influenced on organizational structure, advertisement, and motivation of each employee. Especially advertising seal with the message of ‘Energy Saving A Corporation’ put on each employee’s business card motivated him or her to sell the concept to the customers.

The company won the Best Practice Award (BPA) [7] in 2000 and Japan Quality Award (JQA) [8] in 2001 with one of the groups of business units. That group defined its businesses as ‘Providing with color technology as a total solution’. The reason of winning JQA was the excellence in business processes such as total product development processes coordinated by product managers, information service center (highly evaluated in terms of customer satisfaction), and maintenance service (the shortest maintenance time in Japan), supported by IBUs (independent business units) formed by customer segments.

Authorities awarded some of its subsidiaries and factories in terms of energy saving practices.

Successful products such as LCD modules for mobile phone handsets developed under ‘Saving technology’, inkjet printers developed under ‘Color imaging’, and POS terminals developed under ‘Solution provider’ had contributed the performance of the company.

Market share of its major products increased as well. In domestic inkjet printer market, its share increased from 52.2% in 1998 to 57.3% (No.1) in 2003. In LCD monitor market, its share increased from negligible in 1998 to 14.3% in 2003.

Case2: B Corporation

Corporate and divisional business definitions ‘Building the equipment and systems essential to the modern networked office through *Image Communication*’ was defined as an element of the long-range plan in 1996. The five concepts of the *‘Image Communication’* were ‘Superior imaging’, ‘Open standard’, ‘Appliance-like ease’, ‘Workgroup support’, and ‘Total office coverage’. The business definition had remained unchanged until recently. Based on it, the seven subordinate business definitions were made from the combinations of customers (office, workgroup, and individual user), functions (total office support, superior imaging, and outsourcing), and technologies (image processing technologies, resources for customer support including after service network, and business process expertise) in 1997 based on Abell’s framework. The role of each business definition was clarified and cascaded to business units through the mid-range planning process in 1998. Each definition was firmly supported by at least any one of the business units.

Outcomes in business processes and products By those cascaded definitions, corporate business definition had defused into the whole company and brought

[7] Founded and awarded by Japan Productivity Center for Socio-Economic Development to the company that demonstrates the superior practices in its business processes.

[8] Also, founded and awarded by Japan Productivity Center for Socio-Economic Development to the company that realizes the quality excellence in management to continuously create value to customers.

many superior business processes to the B Corporation. The comprehensive design and production system was introduced to maximize customer satisfactions, halve development lead-time, and minimize total cost. The global production system was established to deliver world uniform quality, supported by Global FPR (field problem report) system [9]. The new SCM system was developed to improve the customer satisfaction and operational efficiency from 1999. The 'CS' (customer satisfaction) management committees were held to get customers' voices involved into management.

The B Corporation got JQA as a whole company in 1999, because of the excellence in its CS management. It was continuously ranked No.1 among domestic copier manufacturers in customer satisfaction survey conducted by JD Power.

Balanced scorecard with five perspectives (financial, customer, internal business process, learning and growth, and environmental protection) installed in 1999 was a measure to realize the functional alignment and a driving force to win the JQA.

It provided customers with products and services such as multifunctional printers to improve the efficiency of networked work group, digital copiers backed up by 'Customer Support System'[10] for domestic customers, and outsourcing services (maintenance, leasing, and consulting) to totally support customer's 'value chain' through the whole business processes.

Market share of its copiers had been maintained 25% from 1998 through 2003 and that of facsimiles had been over 15% during the same period.

Case 3: C Corporation

Corporate and divisional business definitions 'Move the heart and touch the soul, make audio/video entertainment ever more enlivening (*Entertainment Creating Company*)' was the business definition in the long-range plan of 1998, as a result of the corporate identity project, after the new president took over in 1996 to recover from the deficit situation of preceding years. It was formulated by adding employee questionnaire survey results on the original corporate mission 'Make sound and vision warm the heart and stir the soul'. Not only high quality in sound and vision but also entertainment, comfort, and convenience were involved as customer values in the phrase. The top management firmly positioned 'CS' (customer satisfaction) management as the driving force to realize the corporate business definition. Several meetings were held in order to transfer the definition and share the customer value underlying it with middle managers. The four in-house companies cascaded the corporate business definition to their own and down to the products. For instance, mobile electronics related company set the business definition 'Providing customers with advanced mobile life entertainment, challenging for the first in the world'.

Outcomes in business processes and products The employees in the mobile electronics related company shared the definition and strived for creation of the customer value to realize 'advanced mobile life'. The easy-to-operate car navigation systems were developed and sold well. It won JQA in 2002 for its excellence in realization of customer value.

The process management was installed to improve the performance of business

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[9] The reporting system that enables employees to share the quality information over the world.

[10] The diagnostic system linked by telephone lines, that responds to pre-breakdown warnings and repair requests and provides supplies automatically in line with usage level.

processes across the divisions. The CS assessment programs that conform to JQA standard was introduced in 1998. The new SCM system composed of sales forecast sub-system, sales-production balance sub-system, and data-warehouse was developed for the whole group in 2003 to reduce the inventory by refining the sales forecast and production plans.
Balanced scorecard was introduced in 2002 to enhance the realization of the 'CS' management and align each in-house company's mid-range plan to the corporate mission. It had been clearly a supportive factor of high growth rate of the C Corporation.
The successful products under the corporate business definition include car navigation systems, DVD players/recorders, and PDPs.
The C Corporation's market share (in units) in domestic car navigation systems increased from 20.6% in 1998 to 25% in 2003, and that of PDPs increased from negligible to 23.0% during the same period.

Case 4: D Corporation
Corporate and divisional business definitions 'Create things for every kind of imagination', 'Convey emotions and dreams to audiences by the contents, create hardware that achieves the highest standards possible by blending performance, quality, and design, and lead to a home network in which customers can access specific video and audio selections whenever they want, in order to make digital dream come true' was the corporate mission that top management described in the annual report of 1998. The phrases were quoted several times in the CEO's speech in front of middle managers during that year. However, as it was devised to attract shareholders rather than customers or employees without much debate in the company, it had never fully defused into the whole company. In April 1999, in order to realize the mission, organizations related to electronics businesses were regrouped into four in-house companies with 'network' on top of the names of the three (out of four) companies. And each in-house or subsidiary company was directed to build the business models to add value by software (contents) and services rather than hardware itself. Although a few companies cascaded the corporate business definitions to their own, the rest of them did not. The examples of the business definitions that were successfully cascaded from the corporate definitions are 'personal, digital, and entertaining' (personal electronics related company) and 'bringing new ways of fun and enjoyment to homes and individuals' (home game subsidiary). At the same time, a new division that promotes network related new businesses was established to start Internet providing service, IC card business, etc. However, most of the profits still came from conventional stand-alone products such as camcorders, televisions, personal computers, and home game instruments, and many of the network related businesses did not make any clear outcomes. The same types of division in charge of network related businesses were formed and dissolved several times up to 2004. As long as the stand-alone products oriented culture did not change, the corporate business definition was not fully cascaded down to each company.
Outcomes in business processes and products For the managers of in-house companies, the first priority was to maintain the current products that generate the profits, and not to take a risk to enter into unforeseeable network businesses. The idea of building value chain or common platform for network businesses such as CRM database, charge system, and after service measurements (e.g. automatic version-ups of software), was not fully accepted in the whole company.

Innovation around the network business concept was hindered. The concept of music delivery business through Internet to customer's miniature digital recording devices had arisen long before the rival started the similar services, however, partly by lack of integrity as a whole group toward the network value chain concept, partly by too much care of 'DRM' (digital rights management) of software owned by the software subsidiary company, it was not timely realized.
Successful products were limited to camcorders, personal computers, home game instruments, etc.
Its market share (in units) in color televisions (including LCD and PDP systems) decreased from 12.2% in 1998 to 6.1% in 2003, DVD players/recorders from 19.4% to 8.7%, car navigation systems from 13.1% to 10.3%.

Table 3. Case study results of the four companies

		A Corporation	B Corporation	C Corporation	D Corporation
Functionality Score		1.83	1.55	1.48	1.41
Functional Alignment of Corporate and Divisional Business Definitions		Strong linkage between Corporate and Divisional business definitions.	Strong linkage between Corporate and Divisional business definitions supported by BSC.	Strong linkage between Corporate business definition and those of In-house companies supported by BSC.	Weak linkage between Corporate business definition and those of In-house and Subsidiary companies.
Outcomes in Business Processes		Product development, Information service, Maintenance service, IBU system, Advertisement, Energy saving practices, BPA (2000), JQA (2001).	CS management, Design and production system, SCM system, Customer Support System, Global production system, Global FPR system, JQA (1999).	CS management, CS assessment programs, Process management, SCM system, JQA (2002).	CRM database, Charge system, After service measurements were tried to establish without any success.
Outcomes in Products		Successful products: LCD modules, Inkjet printers, POS terminals. Increase market shares in Inkjet printers and LCD monitors.	Successful products: Multifunctional printers, Digital copiers, Outsourcing services. Keep high market shares in Copiers and Facsimiles.	Successful products: Car navigation systems, DVD players/recorders, PDPs. Increase market shares in Car navigation systems and PDPs.	Successful products: Camcorders, PCs, Home game instruments. Loose market shares in Color televisions, DVD players/recorders, and Car navigation systems.
Growth Rate	**FY1997-2003**	4.88	4.04	3.82	1.75
	FY1998-2003	5.98	4.54	4.26	1.99

Notes: Functionality score and Growth rate are taken from Wakabayashi (2005)
Functionality score is scaled from 0.0 to 2.0.
Growth rate is the average annual growth rate of consolidated net sales.

DISCUSSION AND CONCLUSION

In the A Corporation's case, the corporate business definition at the long-range plan made in 1995 precisely reflects the divisional business definitions. Under each divisional business definition, the operational excellence was realized in some business processes and successful products such as LCD modules for mobile phones and inkjet printers were developed, and ultimately they contributed the performance of the company. In the B Corporation's case, the business definition at the long-range plan in 1997 was cascaded to each business unit and it brought favorable performance to the B Corporation through various business processes for CS management and the successful products. In the C Corporation's case, the corporate business definition in 1998 was cascaded to each in-house company, and some business processes and products were successful. However, as the original business definition is not so functional as those of the A and B Corporations, its growth rate is slightly lower than those of the two companies. In the D Corporation's case, the business definition in 1998 influenced the names of some in-house companies and creation of the organization to promote new businesses. However, it was not fully deployed to each group of business units/business unit and did not bear so many successful products. As a result, its growth rate was lower than those of the A, B, and C Corporations. Therefore we conclude that H1 and H2 are proved by our research.

Integrating the results of our preceding research and this paper, we get the following hypothesis,

The company that defines its business by function and cascade it to each group of business units/business unit can continue growing.

We identified the favorable influences of business definitions on business processes supported by JQA records of the A, B, and C Corporations. And the outcomes of the business definitions in products were also identified with the case companies. However, if we try to fully prove the hypothetical causal relationship between the functional alignment of corporate/divisional business definitions, processes, and products and continuous corporate growth as we presented in Figure 1, it will be necessary for us to gather more samples with another approach due to the limitation of interview survey in terms of sample size and objectivity. This part will be the theme of our next research.

The A Corporation's case suggests us an interesting issue. In the A Corporation, corporate business definition in 1995 was inductively derived from the integration of the divisional business definitions. That means the alignment operation should not necessarily be a cascade from the top (corporation) rather it is effective to start from the middle (business units), too. Therefore the following new hypothesis can be drawn,

It is effective to start the functional alignment operation from any level, corporation, groups of business units, or business units.

Therefore for the companies that do not define their businesses by function, it is effective to draw its corporate business definition by inductively from the middle. We will leave the empirical test of the hypothesis to another research.

Another issue is the possibility of applying the concept of functional alignment to BSC. It can be a leading KPI (key performance indicator) of BSC. Also, we might be able to use it as a criterion for evaluating quality excellence in management. We wish to demonstrate these possibilities in our future research, too.

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Emergence of the network structure in the ICT sector

Jukka Hallikas, Jari Varis, Heli Sissonen and Veli-Matti Virolainen[1]

1. Introduction

To meet the needs of customers' a group of organizations with complementary strategies, resources and capabilities link together in a manner that all participants of the supply/ value network benefit. Interest to the industrial networks has increased since various companies and industries have become more dependent on each other. This has resulted in the emergence of entire industry value networks. In this paper our attempt is to address theoretical and empirical foundations for the analysis of industry network dynamics.

One recent research field studying the emergence and evolution of industry dynamics is related to the value network approach (see e.g. Allee 2003). The original objective of the value network framework is to address the tangible and intangible dynamic interchange between various actors in the industry. Furthermore, these networks are often emerged and developed with the collaborative relationships of firms within and across industry value chains and networks. Alliance formation and dynamics is therefore an essential factor in determining the development of these networks.

Important element affecting to the value distribution in network is related to the formation of linkages between organizations in various industries. In the study of Powell, Koput and Smith-Doerr (1996), it was indicated that the position in industry-wide strategic networks and capability to exploit alliance learning is the locus of innovation. Other studies have also described the causal linkages between network position and innovation outputs, e.g. patents (Ahuja, 2000). Furthermore, companies in industry networks may implement different strategies for the involvement in a network e.g. the balance between dependency of internal and collaborative resources.

Industry networks have a finite duration and thus their own life-cycle. While network structure itself is dynamic and constantly changing, it is essential to address the evolution of the networks. Ebers (1999) define inter-organizational networks institutionalize recurring, partner-specific exchange relationships of finite duration

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(often based on goal accomplishment) or of unspecified duration among a limited number of actors. It follows that individual collaborative relationships constitutes the formation and development of network structure.

Our study comprises the development of collaborative relationships in ICT (Information and Communications Technology) sector. What makes the ICT industry interesting in global context is that it is presently under a continuous and at least partially unpredictable change. Different actors such as service operators and infrastructure manufactures are exploiting different strategies for positioning in the industry. This practical consideration provides an important argument for exploring the dynamics of the alliance and network development. In brief, this paper has the following objectives:
To provide a theoretical outline of the structural network and alliance research.
To analyze the evolution of the ICT network in terms of position and power relations at different time spans

In order to outline theories and methods for analyzing the development collaborative relationships, we first provide an overview for the theoretical basis of interfirm networking. From this point, several theories and approaches for explaining the development of networks can be addressed. On the other hand, the strategic choice of positioning in the network seems to be one of the fundamental decisions for the companies involved in an industry network.

We have analyzed the network dynamics and evolution based on the structural analysis of the network by describing the alliance evolution of different actors in case ICT sectors network. This includes the exploration of nature of alliances (alliance activities and participant analyses). We also analyze the actors' structural position in the industry network by adapting the algorithms and UCINET software developed for the structural network analysis. Finally, we compare companies' structural position in the network and their R&D input. This is about to indicate actors strategic positioning in terms of the usage of internal (R&D inputs) and external resources (network position).

2. Theoretical considerations

2.1 Posing the issue

In business thinking the term customer perceived value has had a central position for few last decades. One can argue that different value systems originally stems from concepts of value chain (Porter 1985). Value is not in any ways an unambiguous element. Every company provides customers with an amount of value (Hughes et al, 1998). However, in the scope of the value network research, the phrase is used to describe tangible and intangible benefits that different players in value systems (like end-users) receive from utilizing the product or service. To be successful, company's all efforts must create value for which a customer is ready to pay.

Original Porter's value chain approach is appropriate only in certain circumstances. According to the modern business thinking, in the new business environment such traditional thinking of chain-formed supply organisms is not enough any more. Other types of value concept have to be launched to describe this new wave of doing business. In the figure 1. the continuum of different value systems is described. A value network combines the advantages of a traditional network and value chain activities. When the former emphasizes joint efforts when achieving efficiency, the latter focuses more on the value-creating activities. Term value net is used for example by Bovet & Martha (2000b) and Parolini (1999) and Möller (2003). Term value network is used by (Allee 2000) and (Timmers 1999). Allee (2000) defines the value network: *"A value network is any network or web of relationships that generates tangible and intangible value through complex dynamic exchanges between two or more organizations*. Any group of organizations engaged in both tangible and intangible exchanges can be viewed as a value network".

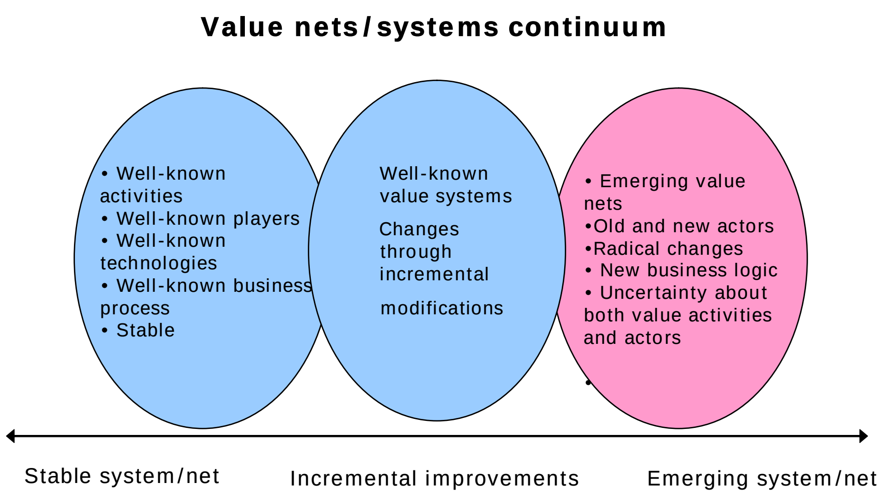

Figure 1. Value nets/systems continuum (Adapted from Möller, 2003)

Right side of continuum is so called future oriented value production system, where radical innovations opening new business opportunities. Different types of dynamic capabilities are then required; for visioning, innovation, network orchestration, and relationship management.

Value needs to be delivered to customers in a way that sustains profitability of the business while meeting fully the expectations of different stakeholders. Achieving this return requires the appropriation of value for stakeholders. Securing a dominant or pre-eminent position in the market place facilitates such appropriation (Hughes et al, 1998). Dominance can come from the superiority of he product offering, its pricing, striking differentiation, control of different dynamic capabilities (see figure 1.) and the ability to exercise power and influence over each of the stages of value system.

2.2 Network dynamics and structure emergence

A modern economy based on knowledge favors customization, flexibility, rapid response and dis-internalization or deconstruction of the value chain (Contractor and Lorange 2002). Rapid technological changes and uncertain environment are motivating firms to form alliances. Powell et al. (2005) combine the motives with the network dynamics in their extensive research in the biotechnology industry. They state in their research that that *older, less-linked organizations are more likely to fail*. On the other hand, Li & Whalley (2002) claim that the transformation from value chains to value networks is evident through the structural analysis. For example, a lot of players from other industries are drawn into the previously neatly defined telecommunications market. This means changes in market positions, strategies and revenue generation. To sum up, it seems that establishing collaborative relationships early enough and expanding these relationships on a regular basis is a key to survive in today's business (Powell et al. 2005).

Our study follows the principles of Powell et al. (2005), Gay & Dousset (2005) and Coviello (2005) who have studied networks from various perspectives. Gay & Dousset (2005) study the growth dynamics and structure of collaboration networks in the biotechnology industry. They adopt a dynamic network visualization approach, which means that time must be conceptualized in the networks. There are two possible ways to analyze time aspect in the networks: discrete and continuous. The former one consists of cross-sectional snapshots of the network, where the focus is on a change from one network state to another. This approach is more beneficial due to the research cost and software issues especially in the longitudinal studies. Gay & Dousset (2005) use the following items in the visualization of the network in addition to the time variation: i) centrality (out degree-, betweenness- and closeness- centrality), ii) turn-over of nodes (network growth), iii) patent data, and iv) technology flows/activities.

Coviello (2005) argues in her study that using both hard and soft factors is required in the network research. This is due to the fact that networks encompass both qualitative and quantitative dimensions, such as processes and structures. Hard factors link mostly to quantitative methods and comprise the structural network analysis while soft factors take into account the qualitative methods and include interactional analysis of the network. The main limitation in the current research on network dynamics is according to Coviello the fact that such longitudinal studies are very limited in number and tend to focus on counting activities or types of network contacts over time. That is, the processes underlying network development are not captured and Coviello suggests tracking and assessing the parallel evolution of both network structure and interactions through a firm's life cycle.

Structural position in a network may provide many advantages to the focal firms. For example the number of indirect ties can be a critical source of information and innovation for a firm (Ahuja, 2000). This is due to firm connection with partners bring also indirect connection to their partners. These connections are likely to provide access to the knowledge of partner's partners in a network (Gulati & Garguilo, 1999). These linkages can be seen as information intermediaries to enhance knowledge and information base of companies, and thus to increase the absorptive capacity of companies i.e. ability to absorb and utilize external knowledge (see e.g. Cohen & Levinthal, 1990). Furthermore, the locus of innovation is often found in networks of learning, rather than in individual firms (Powell et al., 1996). To summarize, there are several benefits associated to the strong structural positions in a network. Therefore, it is important to analyze which companies perform well in the industry network.

While Powell et al. (2005) focused on methods that are applicable to implement a structural analysis, Knoben et al. (2005) analyze the implications of the structural development of the network. The authors have implemented a thorough literature review on (radical) changes in inter-organizational network structures. The authors list several ways in which the network evolution can be approached in research:

- What is the role of change in the network?
- What are the causes and consequences of change in network structures?
- What is the object of change?
- What is the conceptualization of change?
- What is the level of change (dyad or network)?

The importance of structural analysis in studying the network dynamics is described followingly: "This linkage between network dynamics and the evolving structure of fields needs to be made in order to make progress in explaining how the behavior of actors or organizations of one kind influence the actions of organizations of another kind" (Powell et al. 2005, 1139). Later on they highlight the importance of finding out what types of actors and relationships are most critical in shaping the evolution of the field at particular points of time. Li & Whalley (2002) also explain the importance for studying network structures. According to them, the traditional ways of doing business is in change, as the value chains are deconstructed due to companies increasingly outsourcing and collaboration efforts with other companies.

Consequently, companies have become nodes of series of inter-twined value chains, essentially becoming part of a complex and rapidly evolving value network. In order to survive in this new environment, every company needs to understand their positions, and to re-evaluate their strategies and business models. Our paper is focusing on these changes in the dynamic environment of ICT sector, which is described in more detail in the chapter 3.

3. Findings from the ICT sector

As mentioned above, one of the premises of this study is the fast growing and knowledge intensive ICT-sector, where the number of alliances has been steadily growing and the network structure has been evolving. The ICT stands for Information and Communication Technologies and the sector includes the Information Technology (IT) and Telecommunications (TLC) sectors and later also the media industry has seen converging to the ICT sector. When the whole network is analyzed as a whole, there are numerous ways to describe the structure and relations between nodes. Figure 2 provides a rough example of the actor structure of the ICT network, and illustrates different roles in the network

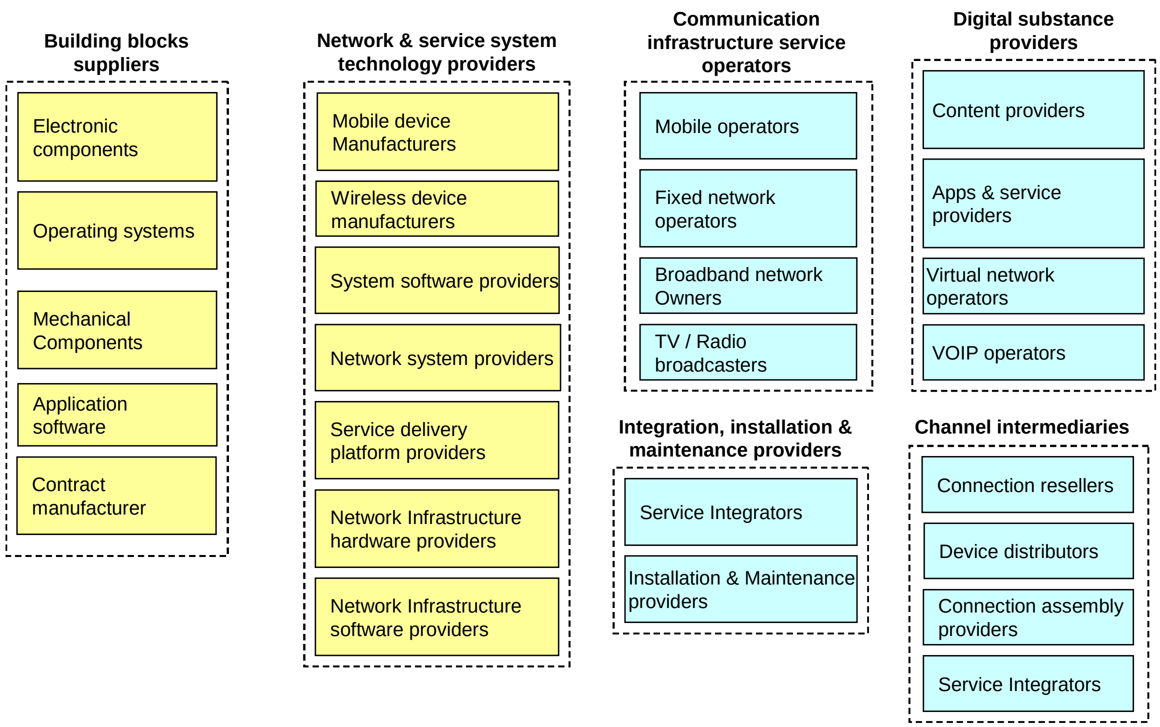

Figure 2. Decomposition of value network into value producers.

3.1 The development of alliance activities

This approach for alliance evolution focuses on the yearly development of alliances between 1998 and 2005 in different ICT groups classified according to the sic codes.

The development of ICT network is displayed in parts, thus focusing on one sic-group at the time. In the following, the operators and communication equipment manufacturers are presented as an example, while the Figures of other groups are listed in the Appendices.

The following figures clarify the development of alliance activities either tied by companies operating in the specific ICT sector (primary sic code of company) or alliances tied in the specific ICT sector (primary sic code of alliance). Additionally, the Figures include information about the orientation of alliance activities: e.g. whether the operators tie alliances within or outside their own business sector (Figures 3 and 4). Another way is to look at the alliances tied in the certain sector: whether the alliances e.g. in the operator business are tied by operators or other companies (Figures 5 and 6).

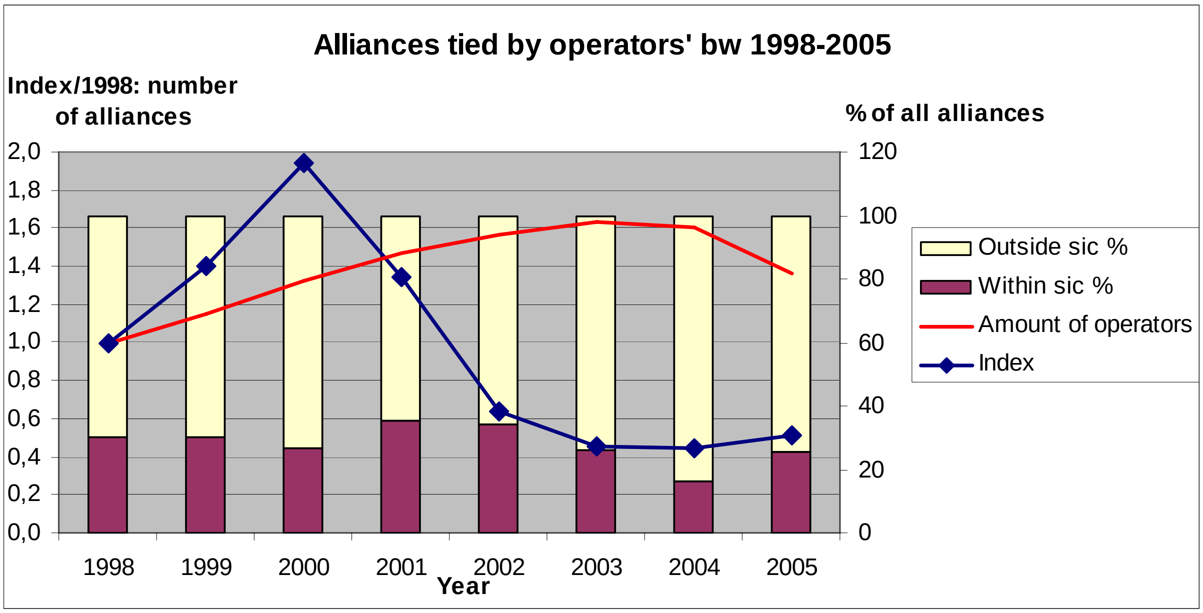

Figure 3. Relative values of alliances tied by operators

By the index-based development of alliances the attention should be paid to the shift in the sic groups of alliances tied by the operators. According to the Figure 3, there are no big differences between the years, only the year 2004 displays clearly smaller portion of alliances tied within the operators' business. The amount of alliances is combined with the number of companies operating in the specific sector. In this way it is possible to exclude the impact of the number of companies on the number of alliances. This means that the alliance strategy was clearly at the top during the year 2000.

3.2 Network structure analysis

We will start the network analysis from the year 1998 and end up till 2005. The starting point was that the latest years in the analysis are the most interesting ones because they tell something about the future trends. First, it was decided to follow the development of alliances year by year. In this way it would be easier to explain which factors may have caused changes in the amount or nature of alliances.

The preliminary runs in the SDC database showed that there was a huge deviation in the amount of alliances in 2000 (so called hype season), which led to compare two different time spans: the hype season (1999-2001) and the stable stage (2003-2005).

Another way is to look at some stable situation: the coopetition analysis, i.e. the comparison between cooperation and competition networks represents this kind of stable analysis. However, it is introduced in this evolution report because it gives an example of how the Ucinet-analysis can be further elaborated.

Approaches to look at alliances

The third issue in the network analysis relates to the different aspects that may be inherent in alliances. First, we could analyze the companies that operate in the certain sic group. In this matter the fundamental question: *where do the companies tie alliances (position of the alliances)?* In other words, we are interested in the *companies'* actions that are placed in certain sic groups. This type of analysis can be divided roughly to two main categories: either the alliances are tied within the same sic group, or the alliances are tied in other sic groups. For example, in the first case the operator tie an alliance within the operator business (i.e., the sic code of the company is the same as the sic code of an alliance), while in the other case an operator ties an alliance that is placed in other sic group (e.g. OEM). This type of analysis does not yet take into account the sic code of the other participants.

Another approach to analyze alliances is to consider *the business* of certain sic group instead of a company perspective as was done in the first case. The following question is posed: *who tie alliances in the certain sic group?* This type of analysis considers two types of alternatives: either the alliances are tied by companies which placed in the same sic group, or the alliances are tied by other companies than those of the same sic group. Also this kind of analysis does not yet take into account, which these companies are who tie alliances in other sic groups than their own.

Additional variables

The amount of alliances during different years does not explain the development of alliances as such. The amount of alliances must be tied to the *number of companies* that operate in the same business (sic group). This information is collected from the Thomson Financial database using the same sic codes as described above.

When illustrating the alliance development, two kinds of perspectives can be included:

- Absolute development of the number of alliances

- Index-based development (the number of alliances is fixed to year 1998)

In the first approach it is possible to compare different industry sectors within ICT. When displaying the amount of alliances and the number of companies in absolute values, it becomes easier to compare the size of different sectors. On the other hand, if we want to compare the yearly development of alliances tied within or outside the business sector, it is better to tie the values to the index (year 1998 represents value 100).

Table 1. Focal companies in the study.

AOL	NTT DoCoMo
AOL TimeWarner	Oracle
Cisco Systems	Qualcomm
Deutsche Telekom	Samsung Electronics
Ericsson	Sanmina-SCI
Google	SBC Communications
Hewlett Packard	Siemens
IBM	Sony
Intel	SonyEricsson
LG Electronics	Telenor
Microsoft	TeliaSonera
Motorola	Vodafone
Nokia	Yahoo

We have analyzed alliance network of 26 companies in order to explore the changes of power structure in the ICT sector. Selected focal companies are shown in Table 1. The selected companies' present variety of actors in ICT sector such as telecommunication manufacturers, telecommunication operators, IT companies, Media companies, Internet service providers and Component manufacturers. All collaborative relationships, either alliances or joint ventures were included in the study. The analysis is conducted in two separate timeframes, 1999-2002, and 2003- 2005 to indicate changes in structural position of companies. The descriptive statistics of the analysis is shown in Table 2.

Table 2. Descriptive statistics of the study.

	Alliance network 1999 – 2001	**Alliance network 2003-2005 (present)**
Amount of relationships	dichotomized relationships	dichotomized relationships
Number of focal firms	26	26
Number of nodes in a network	2016	722

SDC Platinum database and the UCINET program and method were used in the analysis of network structure. The analysis is based on the mapping of relationships and linkages between organizations in a network. The objective is to understand and measure organizations position in a network, based on the analysis of node (company) centrality and structural position in a network.

There are several approaches for measuring centrality in a network. Basically centrality in a network can be seen as an indicator of power. Furthermore, centrality can characterize different positional advantages or disadvantages for an organization in a network. The advantages may be realized for example by having several direct relationships with different actors, or having ties with actors of several relationships. Also position as a broker between collected groups or clusters in the network may provide several advantages for organization in the network.

Perhaps the most simplified measure for the network centrality is the *degree* centrality. It principally measures the number of connection each node in a network has and calculates the degree and normalized degree in the network. The implication of the degree centrality is an activity of a node in the network and it may also indicate hub position in the network. Other important aspect of measuring number of ties is related to the theory of weak ties (Granovetter, 1973), which general thesis is that number of ties influences on the innovativeness of the node in a network.

Other essential measure for analyzing network structure is *betweenness* centrality which is used for measuring the structural position of a focal firm between clusters of nodes in a network. It provides insight to the node's position and role as a gatekeeper between two independent network components. Further, companies who are between clusters of nodes in a network may translate this broker role into power position. Based on the earlier research in network analysis (Everett & Borgatti, 1999), we have used Freemans *betweenness* centrality measure to analyze the shift in the structural position of selected 26 focal organizations in the case ICT network between 1999-2001 and 2003-2005. The results are shown in the Table 3 below.

Table 3. Betweenness centrality measures of 26 focal companies' network

FREEMAN BETWEENNESS CENTRALITIES IN THE NETWORK			
Alliance network (1999-2001); number of nodes = 2016		**Alliance network (2003-2005); number of nodes = 722**	
Firm	nBetweenness	**Firm**	nBetweenness
Microsoft Corp	19,4	Microsoft Corp	16,9
IBM Corp	15,0	IBM Corp	12,9
America Online Inc	7,5	Motorola Inc	10,4
Nokia Oyj	6,0	Samsung Electronics Co Ltd	9,9
Motorola Inc	6,0	Intel Corp	8,6
Sony Corp	5,4	Cisco Systems Inc	7,1
Oracle Corp	5,2	Nokia Oyj	5,3
Cisco Systems Inc	5,0	Sony Corp	4,8
LM Ericsson Telefon AB	4,9	Openwave Systems Inc	4,3
Siemens AG	3,9	Microsoft Network LLC	4,3
Intel Corp	3,6	SAP AG	3,7
Samsung Electronics Co Ltd	3,2	EMC Corp	3,5
Yahoo! Inc	2,5	Oracle Corp	3,4
NEC Corp	2,4	NTT DoCoMo Inc	3,1
Sony Music Entertainment	2,0	Siemens AG	3,0
Hewlett-Packard Co	2,0	Toshiba Corp	2,4

IBM Japan Ltd	1,9	LM Ericsson Telefon AB	2,2
AOL Time Warner Inc	1,8	Fujitsu Ltd	2,0
Hitachi Ltd	1,7	Yahoo! Inc	1,7
Yahoo Japan Corp	1,7	Hewlett-Packard Co	1,7
Toshiba Corp	1,6	Comcast Corp	1,6
Compaq Computer Corp	1,4	CareerBuilder Inc	1,4
NTT DoCoMo Inc	1,2	AOL Time Warner Inc	1,3
LG Electronics Inc	1,2	Google Inc	1,3
Motorola Corp	1,2	Apple Computer Inc	1,2
Fujitsu Ltd	1,2	Avaya Inc	1,2
Deutsche Telekom AG	1,0	LG Electronics Inc	0,7
Telia AB	0,8	Time Warner Inc	0,6
Sonera Oyj	0,6	Vodafone Group PLC	0,5
Telenor AS	0,6	SBC Communications Inc	0,5
Vodafone Group PLC	0,4	Deutsche Telekom AG	0,4
		TeliaSonera AB	0,2

Table 3 summarizes the betweenness centrality measures of the studied network of companies. All companies are not in both analyses since they have not been central or did not exist previously. Originally selected 26 focal companies have been included to the table whether they exist and have above zero betweenness centrality measure. The analysis has been made in two time series, 1999-2001 and 2003-2005 to provide insight to the development of firm's structural position in a network. After UCINET analysis, companies have been listed in ranked order to the table. It follows that companies in the table present higher ranked nodes in the analysis beyond the originally selected 26 focal companies.

The analysis shows that the structural position in the network has not changed much, indicating that companies such as Microsoft, IBM and Nokia that have been strong in the formation of alliance network previously, have continued to create new alliances. This implies to the dynamic strategies towards re-creation of ICT industries. Based on the strong position in betweenness centrality measure, these companies also seek to create collaborative relationships to the industry intersections, and thus position themselves into gatekeepers between company clusters.

Interesting new companies have emerged to the 2003-2005 alliance network compared to the previous one. Some of these companies are new such as Internet search company Google. Also Internet recruiting company CareerBuiler and IP telephony solution provider Avaya represent new and emerging business models within the ICT. Software company Openwave Systems, IP access provider Comcast and computer manufacturer Apple present more traditional players in the sector, however, strong position indicate their attempts to broaden their role in a network.

There are only few operators that have high structural position in the network representing the strong regional scope and relatively small size of operators. Some focal companies such as Telenor, Sanmina-SCI and Qualcomm dropped from the centrality list, because of their low betweens centrality measure in the network. Qualcomm for example is well known for licensing and protecting aggressively its telecommunications digital property rights. Regarding to this, it is not surprising that they are structurally strong in the network of collaborative agreements.

Network position and R&D investment activity

According to McGahan (2004), in constantly changing and developing business environments, like technology-intensive ICT-market, you have to take care of your core value creating assets and to evaluate how quickly these assets are depreciating. In order to analyze the relation between network position and investment in internal assets a data set related to R&D investments of selected companies was collected. Data is based on Thomson One Banker Database (www.thomson.com/financial). An average of R&D investments per sales on three years was calculated, and compared to the network position.

A preliminary regression analysis was done and the companies values on two variables were scatter plotted to illustrate the position of companies in this scale. The data was divided in two sets according to the earlier time frame (1999-2001 and 2003-2005). Data is presented in table 4 and the correlations between the variables in corresponding time frames are presented in tables 5 and 6.

Table 4. R&D investments and Betweenness

	R&D av99-01	Betw 99-01	R&D av 03-05	Betw 03-05	
AOL	2,65	1,80	0,32	1,30	
Cisco	18,69	5,00	14,80	7,10	
Deutsche	1,85	1,00	1,17	0,40	
Ericsson	16,94	4,90	15,52	2,20	
Google			6,94	1,30	
HP	5,72	2,00	4,47	1,70	
IBM	5,70	15,00	5,48	12,90	
Intel	12,15	3,60	13,89	8,60	
Microsoft	16,27	19,40	17,03	16,90	
Motorola	12,49	1,20	11,23	10,40	
Nokia	7,85	6,00	10,65	5,30	
NTT		1,20	3,26	3,10	
Siemens	7,52	3,90	6,80	3,00	
Sony	5,70	5,40	6,60	4,80	
Vodafone	0,72	0,40	0,56	0,50	
Yahoo!	13,20	2,50	11,16	1,70	

Table 5. Correlation between R&D investments and Betweennes in 1991-2001

Correlations

		Betw 99-01	R&D av99-01
Pearson Correlation	Betw 99-01	1,000	,333
	R&D av99-01	,333	1,000
Sig. (1-tailed)	Betw 99-01	.	,123
	R&D av99-01	,123	.
N	Betw 99-01	14	14
	R&D av99-01	14	14

Table 6. Correlation between R&D investments and Betweennes in 2003-2005

Correlations

		Betw 03-05	R&D av 03-05
Pearson Correlation	Betw 03-05	1,000	,573
	R&D av 03-05	,573	1,000
Sig. (1-tailed)	Betw 03-05	.	,010
	R&D av 03-05	,010	.
N	Betw 03-05	16	16
	R&D av 03-05	16	16

Table 7. Correlation between R&D investments in 1999-2001 and Betweennes in 2003-2005

Correlations

		Betw 03-05	R&D av99-01
Pearson Correlation	Betw 03-05	1,000	,470
	R&D av99-01	,470	1,000
Sig. (1-tailed)	Betw 03-05	.	,045
	R&D av99-01	,045	.
N	Betw 03-05	14	14
	R&D av99-01	14	14

The correlations are only indicative as the sample size is very limited. As we can see from the tables 6 and 7 there is some correlation between the figures in the later time frame, and especially if we compare the R&D investments during the 1999–2001 to network position indicator during 2003–2005. The correlation in the latter table might indicate that that R&D investments need some time to realize in stronger network position. As a further illustration of the relation of these two variables a scatter plot are presented in the figure 4.

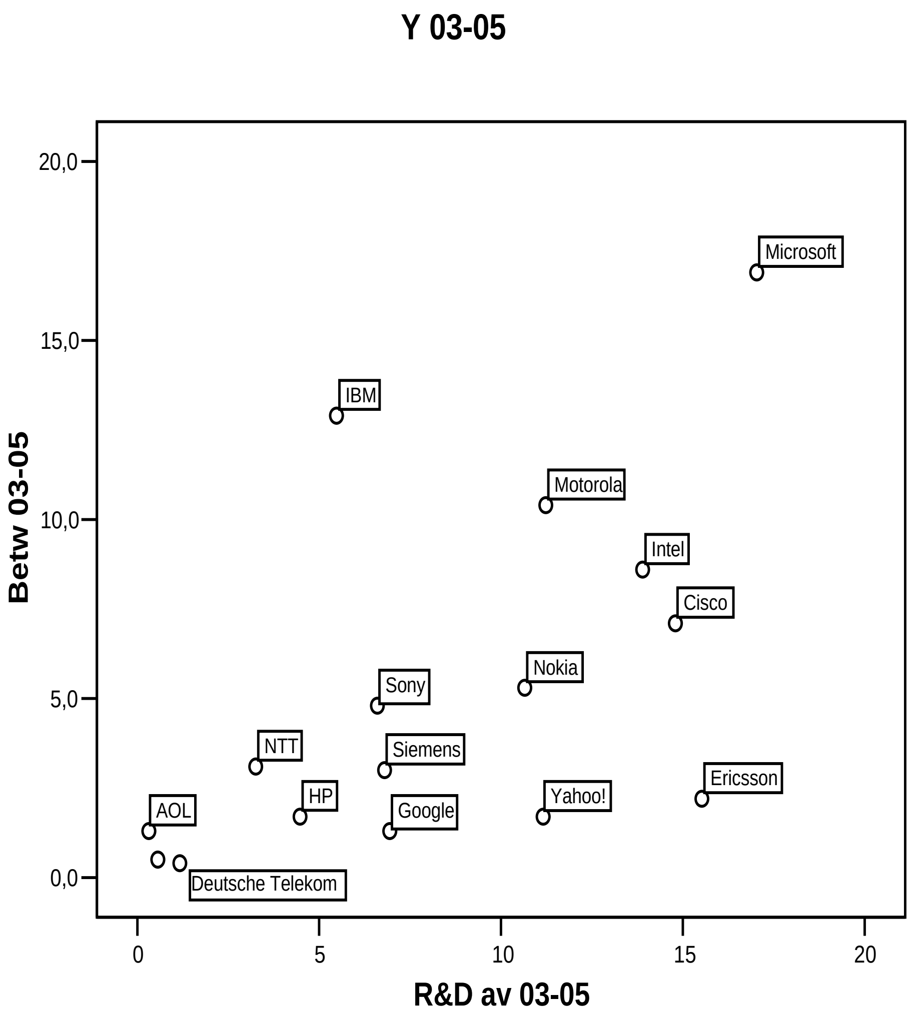

Figure 4. Connection between R&D investments and Betweennes in 2003-2005

There seem to be indications that those companies that invest a lot in R&D also pursue the central positions in their value networks. The scatter plot may be used as a starting point to analyze the company strategies related to the variables. Seemingly Microsoft is a clear number one both in R&D investments and correspondingly has very central position in the value network. On the other hand, operators occupy the lower left corner of the plot with lower figures in R&D investments and less central network position. It can be assumed that companies that are more service intensive do not invest that much in technology development but exploit available technologies in their business. On the other hand, the companies, which can be regarded as hardware producers in ICT sector, are in the center of the plot having relatively high figures in R&D investments, but have more variation in their network positions.

5. Discussion and Conclusions

This study has reported a range of approaches in which to study the evolution of the network by using the ICT sector as an illustrator. Shift in the general structure of the network can be explored in terms of the alliance activities. For example this can be addressed via change in number of alliances tied by actors (operators, communication equipment providers etc.) in a network. On the other hand, it is essential to understand actors' power position within a network. This can be done by studying the actors' structural position in the industry alliance network by applying the algorithms from the social network theory (e.g. betweenness centrality).

It has been indicated in this paper that value networks emerge and develop to large extent through their structure. When considering the theoretical foundations of the development of collaborative alliance networks, the strong position in these networks seem to indicate the external resource orientation. Consequently, it is presumable that strategies of these companies focus strongly on the usage of external resources and they seek to adapt to the changing environment by developing their offerings and innovations complementary with other actors. Drivers of this kind of dependency towards the usage of external resources may be due to standardization and open technological development or the creation of complementary innovations that are beyond the resources available for single organizations in the industry. One driver may also be the ex-ante investments to the internal R&D, which further can be used to absorb knowledge from external sources.

The results of this paper provide indications about the circumstances and effects of the companies' structural position in an ICT industry network. We have also compared firms' position in the network with their internal R&D effort. Companies in the value network are able to develop their resource-based strategies in alignments with these two alternative paths.

Certain limitation of the structural network analysis is the number of companies in the study. Due to ego-centric research approach, it is not possible to give absolutely reliable picture of the structural development of the whole ICT sector. Our study gives, however, indication and insight of the network structure development. Further research could be conducted by including the set of performance metrics to the analysis and with larger sample of companies.

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Disassembly Sequencing Flexibility – A Joint Cellular Disassembly Model

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ABSTRACT
In this paper, we study disassembly sequencing flexibility that means the possibility of interchanging the order in which the required disassembly operations are performed. A mathematical model to design joint cellular disassembly systems is proposed, in which the trade-off between investments in disassembly sequencing flexibility and throughput time performance be considered, starting from a pure belt conveyor line. This model can output (1) how many cells should be formatted; (2) how many workers should be assigned in each cell; (3) and how many workers should be rested in shortened conveyor line. To illustrate the proposed model, numerical simulation experiments based on the data collected from the previous documents are used to estimate the marginal impact each factor change had on the estimated performance improvement.

Keywords: Disassembly, Cell design, sequencing flexibility, Mathematical model.

1. INTRODUCTION
Disassembly is an important activity related with reverse logistics and reverse supply chain. Its purpose includes removing hard parts and hazardous materials, retrieving reusable parts and keeping quality of retrieved materials. Since the directive mandates the treatment, recovery and recycling of all kinds of electric and electronic equipment. Recovery of parts and materials from discarded products has become the responsibility of manufacturers. Whether to obtain useful components for reuse/remanufacturing, to recycle material with economic value or to remove toxic elements, the fact is that disassembly is becoming more and more widespread. Most European countries are now in the process of implementing EU directive 2002/96/EC, governing the facilitation and financing of disposal of Waste of Electrical and Electronic Equipment (WEEE) at their end of life. Until recently, over 90% of WEEE ended up in landfills (Adenso-Díaza et al 2006). Turn about Japan,

the Basic Law for Establishing the Recycling-Oriented Society, which came into force on June 2, 2000, aims at realizing a sustainable recycling-oriented society with less impact on the environment. It was soon followed by the revision of the Law for the Promotion of Utilization of Recycled Resources, which was renamed the Law for Promotion of Effective Utilization of Resources and went into effect on April 1, 2001. Further, the Law for Recycling of Specified Kinds of Home Appliances, commonly known as the Home Appliances Recycling Law, with its associated government and ministerial ordinances ready, came effective in full scale on April 1, 2001. Since then Japanese manufacturers have dealt with electronic home appliances recycling more actively(Association for Electronic Home Alliances 2003). As a result, the recycle rates in 2005 of four main electronic recycle products were reported as air-conditioner 84%, TV sets 77%, Freezer and refrigerator 66%, washing machine 75% (Association for Electronic Home Alliances 2005).

When only a few types of products were disassembled and their values and/or demand volumes were high, a dedicated disassembly line usually was designed to effect system performance. There are several studies in disassembly system design deal with disassembly lines (for example see Gupta and Lambert 2003, McGovern and Gupta 2003, 2004a, 2004b). Basically it was most effective if the recycle conditions were appropriate for disassembly line. However, because the life cycle of the electronic products is becoming shorter (the types of products are changing dynamically), multi-type of products with small batch size and varying schedules should be disassembled flexibly. In this case it may be better to use a cellular configuration that can take into account the variations in the disassembly line. There were also several researches dealt with how to sort the products into disassembly families each of which is processed in a different disassembly cell (Hesselbach and Westernhagen 1999, Das et al. 2000, Tang et al. 2001, Adenso-Díaza et al. 2006). However, so far literature that relates converting exist disassembly line to a new type of disassembly system (includes cell) is rather scarce.

On the other hand, if there were several types of electronic products should be disassembled in the line, the order of operations for all of products might be different. The sequencing flexibility, which means the possibility of interchanging the order of disassembly operations, therefore should be considered in improving the system performance. Recently the sequencing flexibility has been focused on improvement of performance of scheduling rules in job shop. The effects of the *level* of sequencing flexibility, which defined as the number of precedence relationships between product operations relative to the feasible number of operation pairs, were claimed (Rachamadugu et al. 1993, Hutchinson and

Pflughoeft 1994) that a low level of sequencing flexibility already suffices to realize in a substantial improvement of performance of scheduling rules. The sequencing flexibility also has been studied for improving flow shop performance for a variety of shop configurations (Benjaafar and Ramakrishnan 1996). They found that the distribution of flexibility among production stages is as important as the total amount of flexibility – as indicated by the total amount of feasible sequences. Most performance gains result from configurations in which some flexibility is associated with every stage. A more general focus is adopted by studying the allocation and distribution of sequencing flexibility under a variety of shop conditions (van der Zee, and Gaalman 2006). They found that whether sequencing flexibility is relaxed for upstream or downstream stations does not influence performance gains much, and increasing the cell size and the number of cell can lead a marginal increase of the performance gains.

We consider a special case in which a company who has had a belt conveyor line to disassembly their products. When the disassembly environment is changing to varying product types; smaller batch size; varying task size. Their workers have more ability to do the jobs assigned to them before and increasing the motivation of workers is becoming more important as same as increasing the productivity. It is a very practice problem in real reverse logistics environment. Because it was not designed for disassembly cell but for disassembly line firstly in such situations, converting their disassembly line to cell is a considerable choose in their production strategies. However, such conversion differs from traditional disassembly cell design (in which generally clustering similar products in to cells), it can not be redesigned because limited conditions from the working space and labor force. Therefore the concept of sequencing flexibility can be considered to construct the disassembly cell not using the product similarity. i.e., if the disassembly products have sequencing flexibility (the operation tasks can be interchanged) such operation tasks should be constructed into a disassembly cell otherwise remain the tasks in a shortened disassembly line. However when a disassembly line is converted to cells, each cell performs the tasks formerly assigned to numerous stations on the line. The increased number of disassembly tasks performed by each cell worker may increase the time required for each task, which serves to hinder the performance improvement caused by cell conversion. Moreover, because all of workers in disassembly line were not able to have same skill performing those disassembly works, some workers are not appropriate doing those tasks assigned in cells. Those cause resulted some companies did not lead to performance improvements with converting their disassembly lines to cells. Therefore, such conversion is a very complicate decision problem for those companies who wanted to do such conversion.

Our objective is to build a mathematical model to analyze the system performance when a disassembly line is converted to cells. This model can output (1) how many cells should be formatted; (2) how many workers should be assigned in each cell; (3) and how many workers should be rested in shortened disassembly conveyor line, to optimize system performance in a complex disassembly environment. In this paper, complex disassembly environment is considered with multi-product; variant demand; different batch size and the worker abilities are different with work station and disassembly product respectively. We refer the model is as a new disassembly system. Such model can be used as an evaluation tool (i) when company wants to change their disassembly system (usually a belt conveyor line) to a new one (includes disassembly cell manufacturing); (ii) when company wants to evaluate the performance of their converted system.

The remainder of this paper is organized in the following way. We give a brief description of the conversion problem and then build the mathematical model in next section. Using the proposed model, simulation experiments are designed in third section and the result and analysis is given in fourth section. Concluding remarks are given in the final section.

2. PROBLEM DESCRIPTION AND MODELING

We consider following disassembly problem: there exist a traditional belt conveyor disassembly line with multiple disassembly stations. Workers were assigned at each station according to a traditional job design method but they have had ability to do more tasks than that were assigned to them. We assume that the worker's abilities are different with stations and disassembly products. Multiple products will be disassembled in the conveyor line, each product is able to have different batch sizes but with a known distribution of demand. Products should be disassembled by a given scheduling rule like as First Come First Service (FCFS) but with a full batch (i.e., we do not consider batch splitting). When the products are disassembled in the conveyor line, the stations and workers used to complete the disassembly jobs are active. Because workers have different abilities to do those jobs (which belong to stations and products) when the batch will be finished is dependent on the worker with slowest speed to do the jobs. That means the abilities of the other workers were not useful sufficiently, which may lead to decreasing the motivation of workers. On the other hand, all of the products should be disassembled at the same conveyor line with a fixed order; there may be some waiting times in the disassembly processing so that we can not response flexibly to the customer's variant demand. In this paper, we propose KAIZEN methods to improve the system performance of such conveyor disassembly line. Assume that the workers will do all of jobs that they can do even that are not assigned for them, there are several KAIZEN methods be able to implement the disassembly conveyor line. For example, workers who have higher abilities could help other workers in the conveyor line; or converting the conveyor line to some disassembly cells; or converting part of disassembly line to cells for there are frequent flexibilities exist and workers who have higher abilities and remain the part of conveyor line for workers who have lower abilities otherwise.

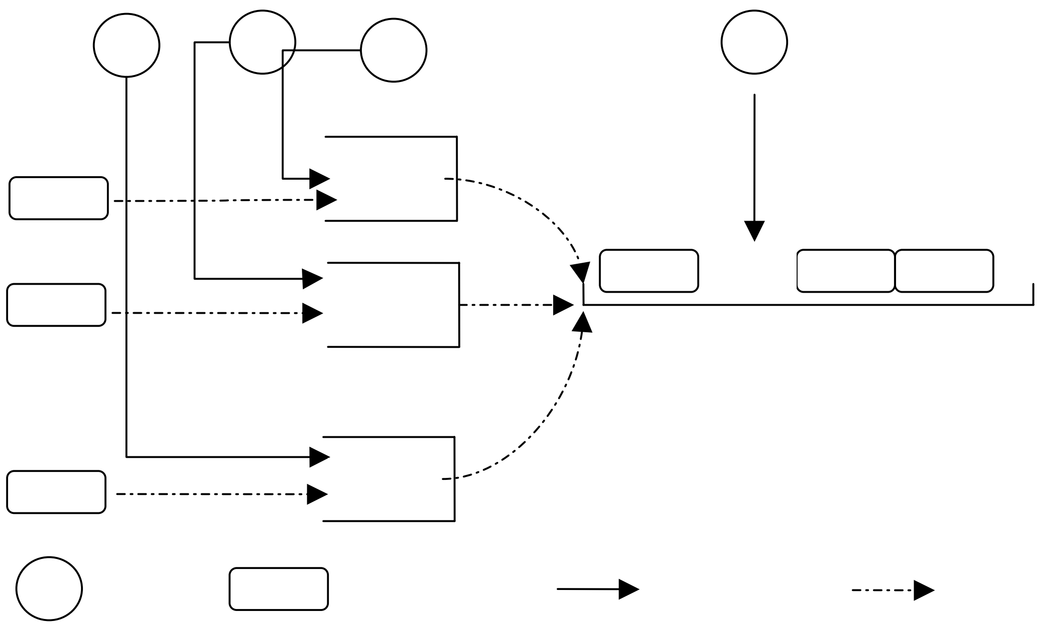

Fig. 1 A hybrid disassembly system

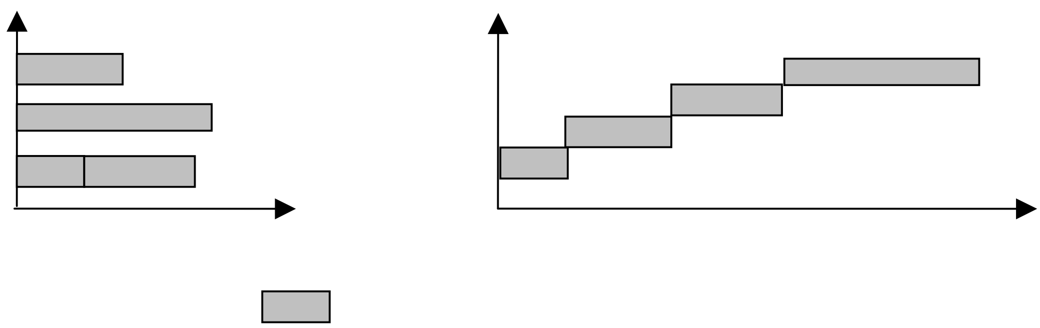

Fig. 2 A case of scheduling in the joint cells+ line disassembly system

In this paper, we consider three types of disassembly systems including pure cell system, pure disassembly line and a joint type of cells + disassembly line. It does not influence the system performance either the cells are set to front or behind of disassembly line(Van der Zee and Gaalman 2006). For simplicity and without lose of generality, we assume disassembly line is formatted behind disassembly cells in the hybrid disassembly system as shown in Fig. 1.

We propose a two step approach to design the disassembly system from Fig. 1. First step is a cell formation approach: if there were only cells formatted in the system (pure cells), we assign all of workers to cells according to their abilities which are different with products and stations (jobs); if there were part of disassembly line be converted to cells, we assign the workers who have higher abilities to cells and remain the workers who have lower abilities into disassembly line. The case of workers can help each other in the disassembly conveyor line just should be considered like as a pure cell in which all workers are assigned in cells. Finally, pure disassembly line is the traditional belt conveyor line.

The second step is a scheduling approach: We use a first come first service (FCFS) rule to assign disassembly product batches to cells or line. In the case of pure disassembly line the product batches are just scheduled according to the order of their coming; in the case of pure cells the product batches are scheduled according to not only the order of their coming but also the ability of workers (that means that product should be assigned prior to the worker (cell) who has higher ability to do the job). In the case of joint system, the product batches are firstly assigned to cells with the FCFS rule, then assigned to CAL with the order calculated by the earliest finish time rule. Fig. 2 shows an example of the joint system with four batches and three cells, where the length of rectangle chart in Fig. 2 states the flow time of that disassembly product batch.

For evaluating the system performance two criteria are considered. Firstly we define total throughput time to represent the system productivity that is the time of all of product batches had been disassembled. That is to say, for given disassembly product mix instead disassembly line the new production system should have a shorter total throughput time. Secondly we define total labor power (hours) to represent the work efficiency that is the cumulative working time of all of workers assigned in the system. Therefore, our problem is to determine the number of cells and number of workers in each cell to minimize the total throughput time and total labor power.

2.1 Problem features and assumption

Following assumptions are considered in this paper to construct the model:

1. Multiple products are planed to disassembly with a product mix.
2. The products are disassembled with different batches and different batch sizes.
3. The types and batches of products are known and constant.
4. The number of tasks is the same to all of product types.
5. If the disassembly system is conveyor line, just one conveyor line is considered.
6. The number of workers is same with the number of tasks on disassembly line.
7. A worker only does one disassembly task in disassembly line.
8. The number of workers in each cell may be different but limited.
9. The number of tasks assigned to each cell is the same.
10. The number of tasks assigned to each cell is at least greater than a constant.
11. A worker assigned in a cell does all the tasks assigned in the cell.
12. A disassembly product batch is just processed in a cell.
13. No setup time between two batches with the same product type in a cell.

2.2 Notations

We define the following terms:

- Indices

i : Index set of workers $(i = 1,2,...,W)$.

j : Index set of cells $(j = 1,2,..., J)$.

n : Index set of product types $(n = 1,2,..., N)$.

m : Index set of product batches $(m = 1,2,..., M)$.

- Parameters

$W_{\max}$: Maximum number of workers in one cell.

$S_{\min}$: Minimum number of stations in one cell.

TB_{nm} : A 0-1 binary variable where $TB_{nm} = 1$, if product batch m is for product type n ; otherwise 0.

B_m : Size of product batch m .

T_n : Standard disassembly time to each task of product type n at each station.

LS_n : Setup time of product type n on disassembly line.

CS_n : Setup time of product type n in cells.

ε_i : Coefficient of influencing level of skill to multiple stations for worker i.

η_i : Upper bound on the number of stations for worker i in one cell, if the number of tasks assigned to workers is over than it, the task time will become longer than ever.

β_{ni} : Level of skill to for worker i for one task for product type n .

- Decision variables

X_{ij} = 1, if worker i is assigned to cell j, otherwise 0.

Y_i =1, if worker i is assigned to line, otherwise 0.

P_{mj} =1, if product batch m is assigned to cell j, otherwise 0.

L_{mr} =1, if product batch m is disassembled by order r on line, otherwise 0.

Z= 1, if line exists in the system, otherwise 0.

- Variables

C_i: Coefficient of variation of disassembly task time of worker i in each cell accounting for the effect of multiple stations.

CT_m: Disassembly task time of product batch m in cells.

FC_m: Batch flow time of product batch m in cells.

FCB_m: Begin time of product batch m in cells.

LT_m: Disassembly task time of product batch m on line.

FL_m: Batch flow time of product batch m on line.

FLB_m: Begin time of product batch m on line.

2.3 Problem formulation

Here we consider the production planning problem which is based on a fixed disassembly product mix with M product batches and N product types. W workers are assigned to the system which may be pure cells or pure disassembly line or a joint type system. Given the upper bound $W_{\max}$ on the number of workers and the lower bound $S_{\min}$ on the number of stations in one cell, the objective is to determine the number of cells and workers in each cell to minimize the total throughput time and the total labor hours. The comprehensive mathematical model is given in Eqs. (1)-(7) as below.

$$MinZ_1 = \underset{m}{Max}\ ((1-Z)(FCB_m + FC_m) + Z(FLB_m + FL_m)) \qquad (1)$$

$$MinZ_2 = \sum_{m=1}^{M}\sum_{i=1}^{W}\left(\sum_{j=1}^{J} P_{mj} FC_m X_{ij} + FL_m Y_i\right) \qquad (2)$$

$$\sum_{j=1}^{J} X_{ij} + Y_i \le 1 \qquad \forall i \qquad (3)$$

$$\sum_{i=1}^{W} Y_i \le W - S_{\min} \qquad (4)$$

$$\sum_{i=1}^{W} X_{ij} \le W_{\max} \qquad \forall j \qquad (5)$$

$$\sum_{i=1}^{W} X_{ij} \le \sum_{i=1}^{W} X_{il} \quad \forall j > l, (l = 1,2,.. J) \tag{6}$$

$$Z = \begin{cases} 1 & \sum_{i=1}^{W} Y_i \ge 1 \\ 0 & \sum_{i=1}^{W} Y_i = 0 \end{cases} \tag{7}$$

Eq. (1) states the objective to minimize the total throughput time of the disassembly product batches assignments. The total throughput time is the due time of the last disassembled product batch. The first part is the throughput time in cells. The second part is the throughput time in line. Eq. (2) states the objective to minimize the total labor hours of the disassembly product batches assignments. The total labor hours are the time of all workers for disassembly product batches. The first part is the labor hours in cells. The second part is the labor hours on line. The detail calculations of the objective functions are represented in the following subsections. Eq. (3) is the rule of worker assignment ensures that each worker should be at most assigned to one cell or line. The sign of inequality means that the worker who has the worse ability is discarded possibly. Eq. (4) is a minimum number of tasks in each cell which means if there is no task in cells, the disassembly system will become traditional disassembly line. Eq. (5) is a cell size constraint because the space of a cell is limited. The value of the maximum number of workers in one cell will be a function of plant size, design and process technology. Eq. (6) is the rule of cell formation ensures that the number of workers in prior cell is greater than that in next cell. Eq. (7) is a flag variable shown whether the disassembly line exists in the system. This rule can lead a smaller search space of feasible solutions but guarantee the optimality of solutions.

2.3.1 Scheduling of batch disassembly in cells

For calculating the total throughput time of the product batch assignments in cells, the disassembly plan will be scheduled with a given scheduling rule under the worker assignments to cells. Firstly, a worker's level of skill is able to vary with the number of tasks. If the number of tasks is over an upper bound η_i, the task time will become longer. This can be represented as bellows:

$$C_i = 1 + \varepsilon_i \max((W - \sum_{i=1}^{W} Y_i - \eta_i), 0) \tag{8}$$

Secondly, the disassemble task times of a product is also able to vary with workers. Consequently, the task time of a product is calculated by mean disassembly task time of all workers in the same cell. Actually, the task time of product batch m is represented via following equation:

$$CT_m = \frac{\sum_{i=1}^{W}\sum_{j=1}^{J}\sum_{n=1}^{N} T_n \beta_{ni} TB_{mn} P_{mj} C_i X_{ij}}{\sum_{i=1}^{W}\sum_{j=1}^{J} P_{mj} X_{ij}} \tag{9}$$

Then, using the FCFS rule, the flow time FC_m and begin time FCB_m of product batch m is represented as below.

$$FC_m = \begin{cases} CT_m (W - \sum_{i=1}^{W} Y_i) \left\lfloor \frac{B_m}{\sum_{i=1}^{W}\sum_{j=1}^{J} P_{mj} X_{ij}} \right\rfloor + \sum_{n}^{N} CS_n (1 - \sum_{j=1}^{J} Y_{(m-1)} Y_{mn} P_{(m-1)} P_{mj}) & m > 1 \\ CT_m (W - \sum_{i=1}^{W} Y_i) \left\lfloor \frac{B_m}{\sum_{i=1}^{W}\sum_{j=1}^{J} P_{mj} X_{ij}} \right\rfloor + \sum_{n}^{N} CS_n \sum_{j=1}^{J} Y_{mn} P_{mj} & m = 1 \end{cases} \tag{10}$$

$$FCB_m = \sum_{s=1}^{m=1} \sum_{j=1}^{M} FC_m P_{sj} P_{mj} \qquad \forall m \tag{11}$$

$$\sum_{j=1}^{J} P_{mj} = 1 \qquad \forall m \tag{12}$$

$$FCB_m \le FCB_{m+1} \qquad \forall m \tag{13}$$

$$\sum_{m=1}^{M} C_{mj} = 0 \qquad \sum_{i=1}^{W} X_{ij} = 0, \forall j \tag{14}$$

Where, Eq. (10) states the flow time of product batch m. The first part is the process time and the second part is the setup time, where $\left\lfloor \frac{B_m}{\sum_{i=1}^{W}\sum_{j=1}^{J} P_{mj} X_{ij}} \right\rfloor$ presents the upper integer number of products for each worker in the same cell. Eq. (11) states the begin time of each product batch. There is no wait time between two product batches so that the begin time of one product batch is aggregation of flow time of all of the prior product batches which are in the same cell. Eq. (12) is the assignment rule in which a product batch is just only assigned to a cell. Eq. (13) is the rule of scheduling FCFS constraint that means the prior product batch must be assembled before the next product batch. Eq. (14) are the rule of assigning constraints, that means a product must be assigned to a cell in which a worker is assigned at least.

2.3.2 Scheduling of batches production in line

For calculating the total throughput time of the product batch assignments in line, the disassembly plan will be scheduled with a given scheduling rule under the worker assignments to line. Of course, if all workers are assigned to line, that is the traditional disassembly system, otherwise, that is a joint disassembly system. Here, the task time is calculated by the longest task time among the workers on line. Actually, the task time of product batch m is represented via the following equation:

$$LT_m = \sum_{n=1}^{N} \max(T_n \beta_{ni} TB_{mn} Y_i) \tag{15}$$

Then, using the FCFS rule, the flow time FL_m and begin time FLB_m of product batch m is presented as below.

$$FL_m = \begin{cases} \sum_{i=1}^{W} Y_i \sum_{n=1}^{N} T_n \beta_{ni} TB_{mn} + LT_m (BS_m - 1) + \sum_{n=1}^{N} LST_n (1 - TB_{(m-1)n} TB_{mn}) & m > 1 \\ \sum_{i=1}^{W} Y_i \sum_{n=1}^{N} T_n \beta_{ni} TB_{mn} + LT_m (BS_m - 1) + \sum_{n=1}^{N} LST_n TB_{mn} & m = 1 \end{cases} \tag{16}$$

$$FLB_m = \max(FCB_m + FC_m, FLB_K + FL_K) \qquad \left\{ K \middle| \begin{array}{ll} L_{mr} = 1, L_{K(r-1)} = 1 & r > 1 \\ L_{kr} = 1 & r = 1 \end{array} \right. \tag{17}$$

$$\sum_{m=1}^{M} L_{mr} = 1 \tag{18}$$

$$\sum_{r=1}^{M} L_{mr} = 1 \tag{19}$$

$$L_{m_1 r} FLB_{m_1} \geq L_{m_2 (r-1)} (FLB_{m_2} + TL_{m_2}) \qquad \forall m_1, m_2 \in M \tag{20}$$

Where, Eq. (16) states the flow time of product batch m, the prior two parts are the flow time of product batch m, the third part is the setup time of product batch m. Eq. (17) states the begin time of each product batch. If the disassembly system is the joint model, the waiting time between two product batches will be considered, otherwise no consideration for waiting time. In the joint model, the begin time of product batch m is the maximum value between the end time of the prior product batch on line and the end time of product batch m in the cell. In the disassembly line model, the begin time of product m is the end time of the prior product batch which is ordered by the FCFS rule. Eq. (18) ensures that a product batch is assigned to one order. Eq. (19) ensures that a order is assigned with a product batch. Eq. (20) ensures that the begin time of a product batch must be later than the end time of the prior product batch.

3. NUMERICAL SIMULATION EXPERIMENTS

For a given number of workers (*X* + *Y)*, the objective functions are not linear but bounded. Hence, we must conduct an exhaustive search over *X* + *Y*. Since there are (*X*+*Y*) major loops for cell formation and *J* minor loops for scheduling, for practical values of *X* + *Y* and *J* it is not computationally intensive. The purpose of this paper is to compare the performances of cells and disassembly line under complex production environments. We do numerical experiments to simulate the effects of each of factors influenced on the performance of disassembly system based on the model proposed above. For comparison of the performance between new systems and traditional disassembly line, the percentage changes are determined as follows:

$$TTPH = \left(\frac{TTPH\ \ of\ \ CM - TTPH\ \ of\ \ CAL}{TTPH\ \ of\ \ CAL}\right) * 100$$

$$TLH = \left(\frac{TLH\ \ of\ \ CM - TLH\ \ of\ \ CAL}{TLH\ \ of\ \ CAL}\right) * 100$$

3.1 Parameters design

Table 1 and 2 show the parameters used in the experiments. As shown in Table 1, the first parameter is the level of skill with multiple tasks. The η_i value is used to control if someone's level of skill will happen to change, which is assumed to be 10. The ε_i value is used to control the variability, which is based on a normal distribution with a mean value 0.2 and the standard deviation 0.05. Simply, the inter-arrival time is neglected here. The second and third parameter is the setup time of the cells which is smaller than that of the line. The values of them are separately 1 minute and 2.2 minutes. Simply, the setup time of the line in the joint model is also the same with pure disassembly line. The fourth parameter is the standard task time, which is assumed to be 1.8 minutes. The fifth and sixth parameters are separately maximum workers values in a cell and minimum tasks values needed in a cell. It is assumed that there are some constraints in the disassembly system, the values 5 and 2 are assumed. The seventh parameter is the number of cells given by 10, because the biggest number of tasks in this experiment is 20 and 2 tasks must be assigned to each cells, the value over than 10 is meaningless.

Table1. Experimental parameters

Parameter	*Value*
Level of skill with Multiple Tasks((η_i, ε_i))	10, Normal($\mu = 0.2, \sigma = 0.05$)
CAL(LS_n)	2.2 minutes
CM (CS_n)	1 minute
(T_n)	1.8 minutes
$W_{\max}$	5
$S_{\min}$	2
J	10

As shown in Table 2, the worker's level of skill to product type is assumed to be a normal distribution with the mean value 1 and the range of standard deviation from 0.1 to 0.3.

Table2. Worker's Level of skill(β_{ni})

Product Type				
1	2	3	4	5
N(1,0.1)	N(1,0.15)	N(1,0.2)	N(1.0.25)	N(1,0.3)

N(1,0.1): Normal distribution($\mu = 1, \sigma = 0.1$).

Table3. Experimental factors

Factor	*Product Type*	*Product Batch*	*Batch Size*	*Task Size*
Product Type	1,1-2,1-3, 1-4,1-5	6	50	12
Product Batch	1	3,4,5,6, 7	N(50,5)	12
Batch Size	1	6	N(10,5),N(30,5),N(50,5) ,N(100,5), N(200,5)	12
Task Size	1	5	N(50,5)	5,10,12,15,20

3.2 Factors design

For comparing the performance among the different disassembly system, four kinds of disassembly system were considered, which included Best CM, 2 workers CM, 3 workers CM, 6 workers CM and pure disassembly line. There are a lot of out side factors which can influence the system performance. A brief overview of four factors used in the experiments is given in Table 3.

(1) Product type

Since disassembly line is designed for single product at first, it can be considered the performance of disassembly line will become worse when the product type changes to be multiple. We set five situations, in which the number of product type ranged from 1 to 5, to confirm this supposition. In this way, the higher variability of level of skill will happen with more product types in the disassembly system according to the parameters set above.

(2) Product batch

Even disassembly line is suitable to single (less) product type, product batch is still influencing the system performance. It can be considered that disassembly line is better in a less product batches environment, and become worse when the product batches increase. From this view point, different number of product batches will be arranged for investigating the effect on different disassembly system.

(3) Batch size

The values of batch size are set by range from 10 to 200. In this way, the effects on the systems above with the different volume of batch size can be investigated.

(4) Task size

Cross-training of workers is a significant factor which effected on disassembly cells. Through the cross-training, the level of skill to deal with multiple tasks becomes higher than ever. With this consideration, the different task size is assumed from 4 to 20, while the lower bound on the number of multiple tasks is fixed by 10. If the task size is greater than 10, the standard task time will become longer than ever. The effect of worker's ability to deal with multiple tasks on the performance of disassembly systems will be investigated with this experiment.

4. RESULTS AND DISCUSION

Several simulation results are obtained from our experiments. Here we just show some main observations from the standpoint of minimization of total throughput time with the constraint of the total labor hours.

4.1 Product type

Fig. 3 and 4 show the percentage changes of the two system performance measures with the increasing of product type.

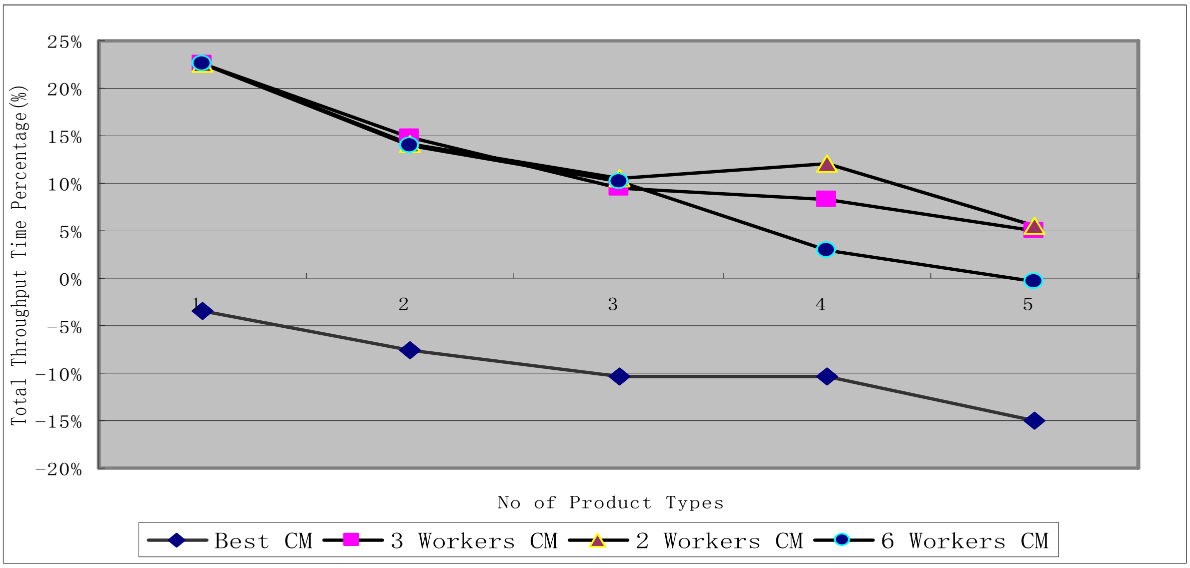

Fig. 3 TTPH with different product types

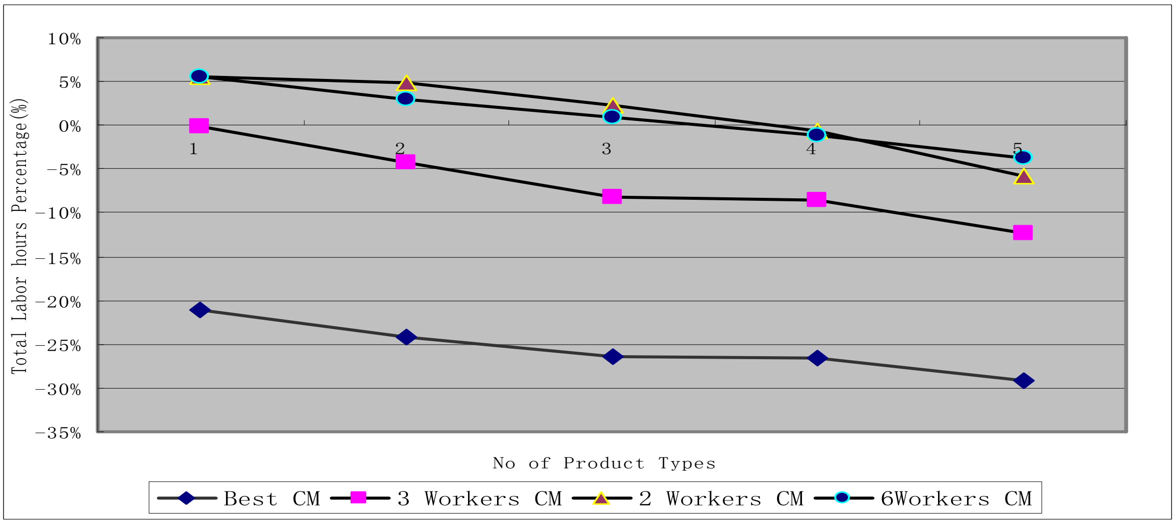

Fig. 4 TLH with different product type

From the viewpoint of TTPH (Fig. 3), generally the percentage changes of all the cell systems are decreasing when product types are increasing. That means increasing of product types leads better performance in cell system but worse performance in disassembly line. However, except Best CM, the performances of 2 workers CM, 3 workers CM, 6 workers CM are not able to exceed that of disassembly line in the experimental situation. The solution of Best CM is varying with product types, especially when the product type is 5 the Best CM is two 5 workers CM + 2 workers line and achieve maximum 15% improvement in total throughput time. It should be noticed that all of the workers in the line also be assigned in the Best CM. But in the case of Best CM, several workers do their jobs each other according to their abilities and only the workers who have not had cross training are remained at the rested line.

Consider the constraint of TLH (Fig. 4), increasing of product types also leads better performance in cells than that in the line. When product types are over 4 all of cell systems can improve the performance of total labor hours in the experimental situation.

5.2 Product batch

Fig. 5 and 6 show the percentage changes of the two system performance measures with the same product type and the increasing of product batch.

From the viewpoint of TTPH (Fig. 5), because disassembly line is originally designed for single product type, rather the performance of cell systems are varying significantly but can not exceed that of the line in the experimental situation. Especially it can be observed from Fig. 5 when the product batch is over 5 the Best CM can achieve performance improvement in total throughput time. The solution of Best CM is two cells in which 9 workers are assigned and 3 workers are remained in line.

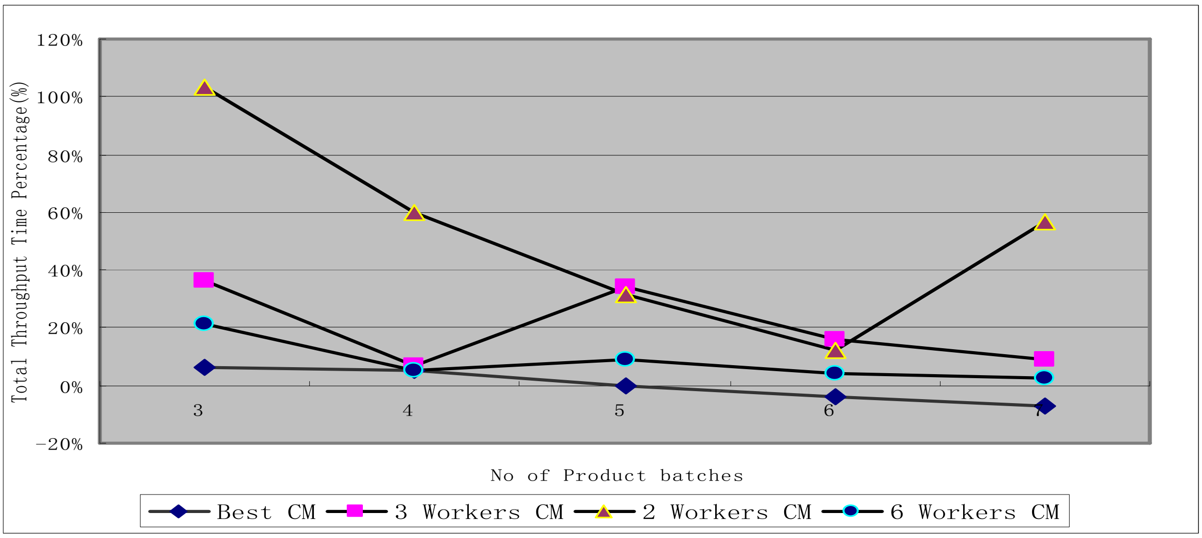

Fig. 5 TTPH with different product batch

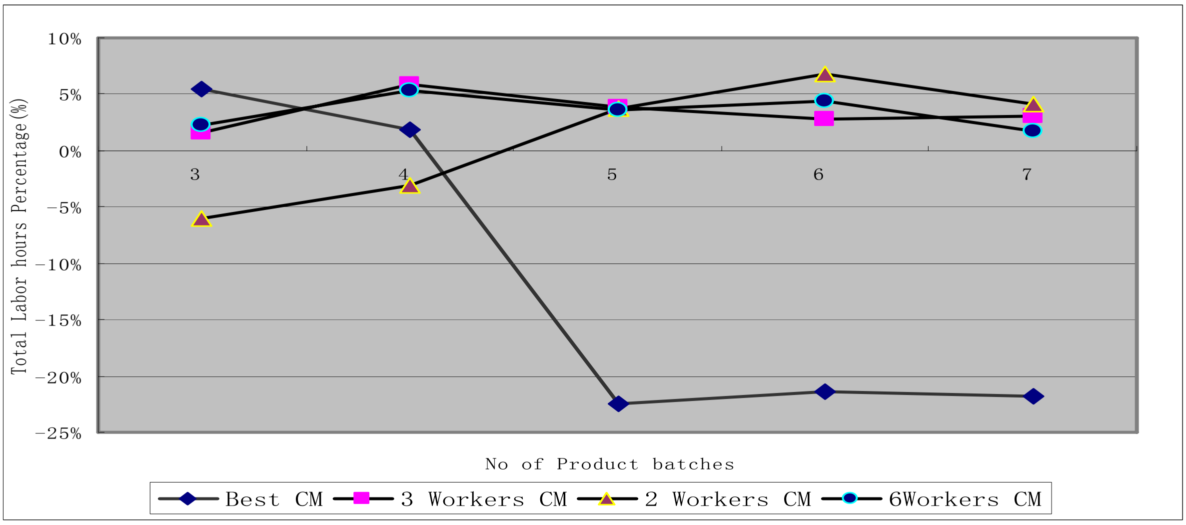

Fig. 6 TLH with different product batch

Consider the constraint of TLH (Fig. 6), increasing of product batch is not able to lead better performance in almost of cell systems than that in disassemblyline except the Best CM. When product batches are over 4 the Best CM can achieve about 25% performance improvement in total labor hours in the experimental situation.

5.3 Batch size

Fig. 7 and 8 show the percentage changes of the two system performance measures with the increasing of batch size.

From the viewpoint of TTPH (Fig. 7), when the batch size is small (<30) almost of cell systems had better performance than that of disassembly line. However, when the batch size is becoming larger (over 50) the performances of cell systems are becoming worse and worse than that of disassembly line, including the Best CM. The reason is that the bigger batch size will reduce the influence of setup time and waiting time.

Consider the constraint of TLH (Fig. 8), when the batch size is small (<30) all of cell systems had better performance than that of disassembly line. However, when the batch size is becoming larger (over 50) the performances of cell systems are becoming worse and worse. Observably, even the batch size increased to 200, the Best CM still can achieve about 13% performance improvement in total labor hours in the experimental situation.

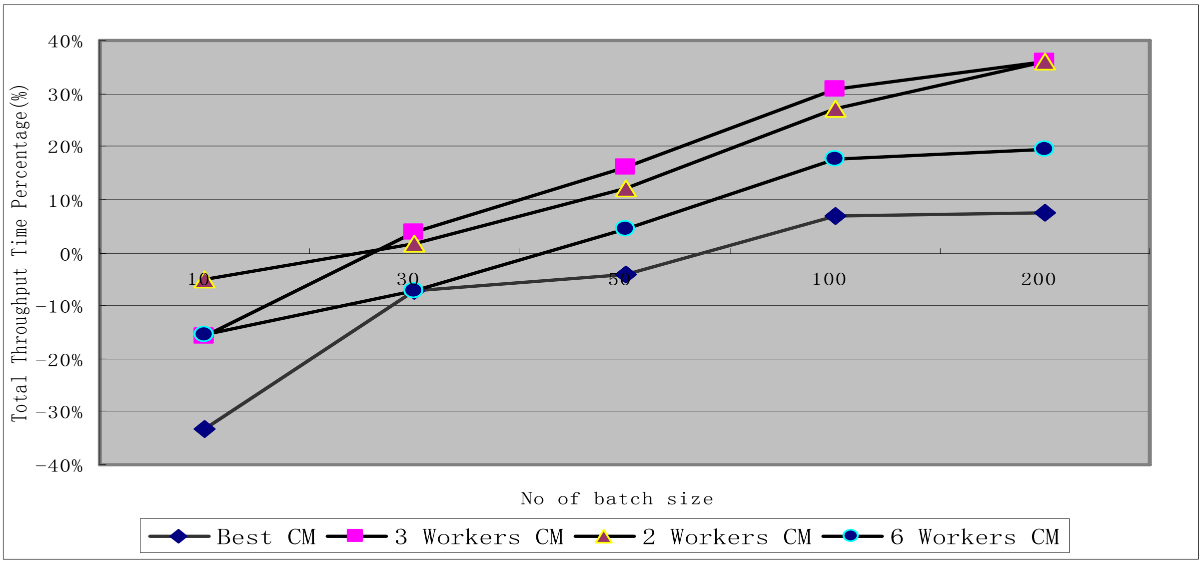

Fig. 7 TTPH with different batch size

Fig. 8 TLH with different batch size

5.4 Task size

Fig. 9 and 10 show the two system performance measures (note here not use the percentage changes) with the increasing of task size. Here we just compare the performance between the Best CM and disassembly line because such comparison can clarify the essence of the conversion. The solution of Best CM is that there are three cells in which 9 workers are assigned and 11 workers remained in the line.

From the viewpoint of TTPH (Fig. 9), increasing of task size indicates that there exists a break point at which the cell system turns better performance to worse than disassembly line. The main reason is that the worker's level of skill becomes lower when he must deals with the task size over his ability so that the task time will become longer. The break point is depended on the worker's level of skill bounded by the task number η_i .

Consider the constraint of TLH (Fig. 10), there also exists a break point at which the cell system turns better performance to worse than disassembly line. The difference is the break point in TLH appears later (task size equals 17) than that in TTPH (task size equals 5) in the experimental situation.

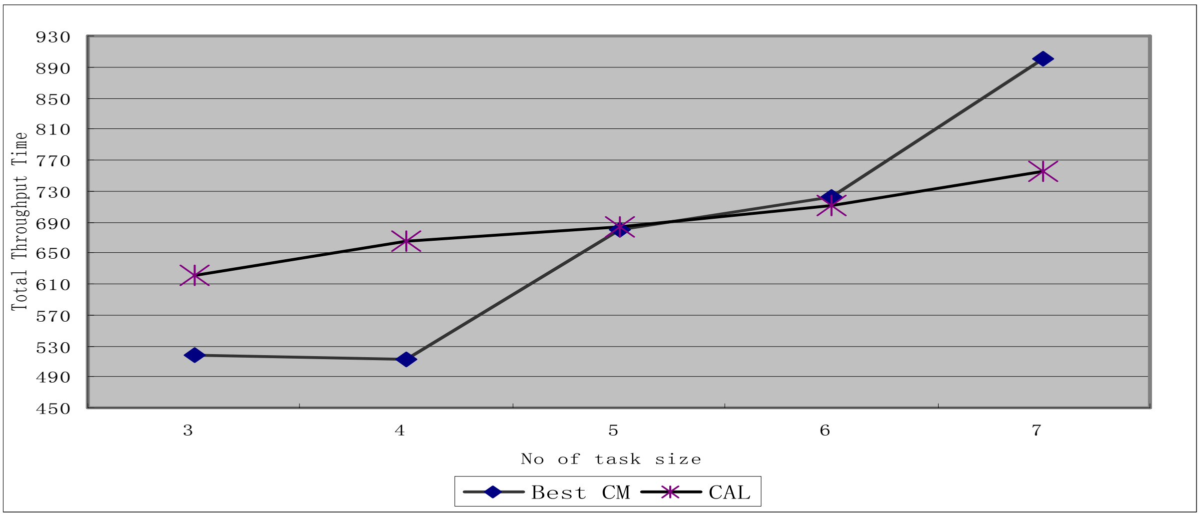

Fig. 9 TTPH with different task size

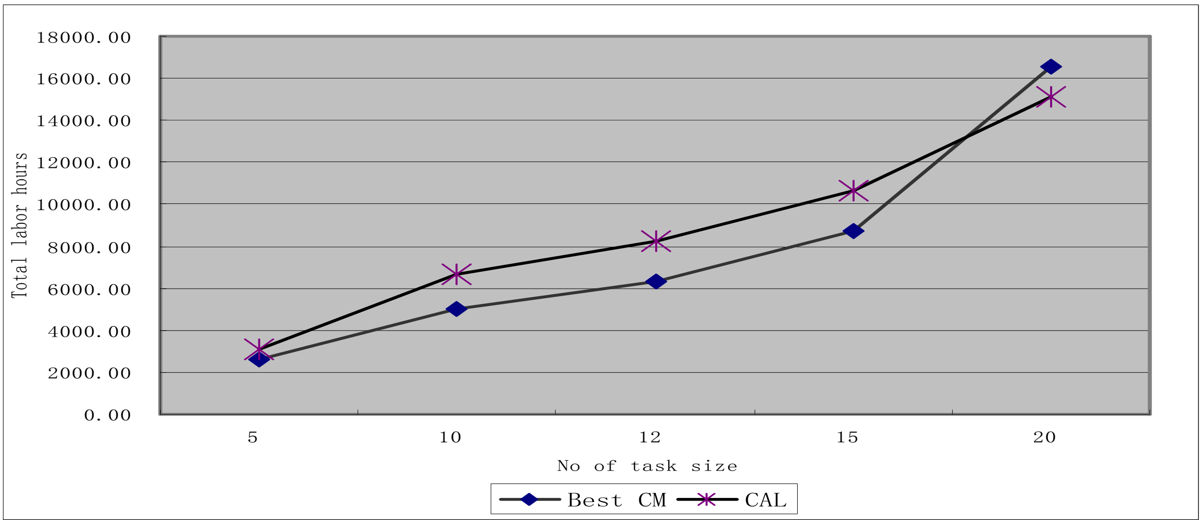

Fig. 10 TLH with different task size

Generally, it can be considered that the joint model is appropriate for the first conversion, then how many cells should be designed and how many workers should be assigned in each cell are becoming a very important decision making problem. Too workers in one cell (big cell) or too cells in the disassembly system is not the best layout.

4. SUMMARY AND CONCLUSIONS

Constructing cell layout into disassembly line is a new kind of technical innovation. The main contribution of this paper is building a mathematical model to construct the conversion using sequencing flexibility. Using this model we can not only design a new disassembly system but also evaluate the performance of converted system. Simulation experiments have given clear insights of various factors which influence the system performance.

There are a lot of researching works will be done in the future. The optimal calculating algorithms should be developed for solving practical size problems. Because the problem is NP hard some meta-algorithms (e.g., GA) also should be developed to overcome the limit of optimization methods. The multi objective optimization also should be carried out for the model whereas they were considered separately in this paper. Moreover, the scheduling rule used in this paper is FCFS and it is a very important factor in the model. So that other dispatch rules (e.g., SPT(shortest production time)) also should be considered be used and evaluated in the model.

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INFLUENCES OF INSTITUTIONAL ENVIRONMENT TOWARD THE DEVELOPMENT OF SUPPLY CHAIN MANAGEMENT

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ABSTRACT

The development of supply chain operational performance in global context is often limited by some of the institutional constrains. In order to enhance the ability of supply chain operational performance, it is essential for the focal company to understand the institutional environment of the supply chain members. The proper institutional arrangement should be, furthermore, positioned to induce cooperation and motivate all chain members to participate activities which produce reciprocal benefits. The research on supply chain operational performance has been carried out in Japan, Thailand and China. The findings indicated that the institutional environment would play important roles in the current performance level and could be one of the main obstacles in improving the supply chain operational performance. In addition, the companies with similar institutional environments were observed to have common way of thinking with respect to supply chain management perception.

INTRODUCTION

In view of the fact that business management in 21st century has encountered the inter-network competition, individual business has no longer competed as solely independent entity, but rather, as a supply chain. Henceforth, innovation in supply chain is required for efficient supply chain integration. However, numerous factors are considered to affect supply chain innovation. In particular, the regulatory, normative, and culture cognitive elements of institutional environment around the world could either improve or impede the ability of supply chain partners which results directly in the operational performance of the entire supply chain (Frohlich and Westbrook 2001, Closs and Mollenkop 2004). The surveys on supply chain operational performance were conducted in Japan, Thailand and China in order to verify if manufacturing sector from these countries perform at different performance levels and what area they currently focus. The result implies that the discrepancy in the institutional environment may influence the level of supply chain operational performance in some specific areas. Furthermore, this reseach attemps to identify the position of each company in different business environments, e.g. in develped or newly industrialized developing countries. The underline on firm ownership status has motivated researchers to explore their feature and viewpoint regarding SCM development. As such, seven categories from four countries which are Japan, Thai Multinationals, Thai Locals, China State Owned Enterprises (SOEs), China Foreigns, China Privates, and reference data from Finland, are thoroughly investigated. The projected position using multidimensional scaling method would identify similarity and disparity among these groups.

THEORETHICAL BACKGROUND AND HYPOTHESIS

The development of SCM could be achieved from the co-evolution between proper supply chain innovation and suitable institutional arrangement which is referred to as "Institutional system". Supply chain innovation includes the selection of appropriate information technology, logistics procedures and marketing procedures which suit for different supply chain operations in each unit. However, some investment and changed activity sets are required for successful innovation in the supply chain such that firms are reluctant to participate in an innovation unless they could gain adequate benefits. Meanwhile, the institutional arrangements are necessary to support the supply chain innovation. Institutional environment of supply chain should be well comprehended before proper institution arrangements such as new contracting, ownership realignment are allocated. The conceptual framework of SCM development in global market channel which was partly modified from Benlo et al. (2004) is exhibited in Figure 1.

Referring to the conceptual framework, Institutional Environment (IE) is one of the most significant factors for an achievement of SCM development. It was recognized as an integration of various building blocks of a national setting and context. Forces within an IE may pressure local firms to maintain traditional channel systems that are suboptimal for the perspective of supply chain development (Benlo et al. 2004). In particular, institutional theorists (Scott, 2001 and Grewal and Dharwadkar, 2002) acknowledged that IE is composed of predominantly three components Regulative, Normative, and Cultural-cognitive.

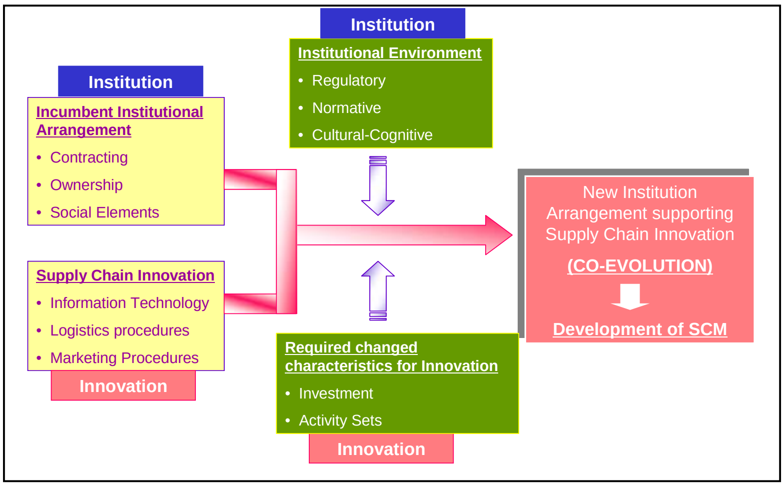

Figure 1. Conceptual framework of SCM development in global market channel (inspired by Benlo et al, 2004)

Regulative element refers to the demands of governments and regulatory bodies to comply with laws and other requirements such as government constrains which inhibit the development of modern logistics in China in the sense of underdeveloped infrastructure (Jiang, 2002). *Normative* element mentions about the society's values and norms that direct behavior through social obligations and expectations (Scott, 2001). The normative is always exposed in terms of countries' social believes or business behavior, for example, the strong loyalty among existing partners in Japan. Although new business partners may be considered more advantageous for the focal firm, they could not easily replace or enter as a new member of the chain. The last dimension of IE is *Cultural-cognitive*, which refers to a common framework of individual society that has been formerly created. It was later brought about "Prefabricated organizing models and script of actions" for society (Scott, 2001). Sometimes, the cultural cognitive may negatively impact the willingness and ability of the firm for institutional arrangement.

Typical institutional environments which could improve or impede supply chain performance of Japan and China have been reported by various researches (Benlo et al., 2004, Armstrong and Tan, 2001, Grewal and Dharwadkar, 2002, Jiang 2002, Jiang and Prater 2002). However, very limited investigation has been undertaken for Thailand's context. Jiang and Prater (2002) pointed out on their finding that in the case of China, the *Regulatory* element of IE is delicate, and greatly restricts the ability of foreign and domestic firms to adopt supply chain innovation. The government constraints have slowed down the development of SCM in the sense of China's underdeveloped infrastructure, government regulations and disintegrated distribution channel throughout China. Upon discussion on *Normative* element, for example in Japan, authorizing and acquisition mechanism have led many domestic Japanese firms to conform with traditional practices that have resulted in long channels and strong loyalty among existing partners (Lohtia and Murakoshi, 1999). Accordingly, domestic channel members are unwilling to change and highly dubious of unfamiliar practices, resulting in inefficient supply chains when viewed from the perspective of supply chain innovation. This observation was inline with the *Cultural-cognitive* element which has shaped the decision making on SCM in many societies. For example, Japanese culture uniquely supports the "Keiretsu", a highly coordinated family of independent firms linked by long-lasting, nearly unbreakable bonds (Benlo et al. 2004). Relying on group loyalty and centralized control from a dominant firm, managers of those Japanese firms are unable or unwilling to accept the flexibility and adaptive arrangement with non-members which are often required by supply chain innovation. In turn, Chinese culture is uniquely characterized by the need for "Guanxi" or personal connections (Jiang and Prater, 2002). Despite technological advantages, a supply chain innovation will not be adopted unless the focal company can access "Guanxi" based relationship. As such, the strong reliance on personal connection among the Chineses can greatly impede the development of SCM and logistics innovation in this country.

It is conclusive from the previous literatures that the Institutional Environment plays an important role in the development of supply chain management. This paper will discuss how IE could affect a performance of supply chain operations. Supply chain operational performance of business sector from the three countries was successively investigated. For comparison purpose, Japan symbolizes developed country while Thailand and China represent newly industrialized developing countries at a different scale. As a result, the following hypothesis is derived.

<u>Hypothesis 1</u>*: The Supply chain operational performance level between Japan Thailand and China is different which may be influenced by different institutional environment.*

In the context of developed and developing countries, two arenas have been classified by many decisive factors such as degree of industrialization, standard of living, GDP per capita or basic infrastructure (Kirkpatrick, 2006). Delayed modernization and weak industrial economic sector are commonly found in the developing country, hence management and technological know-how are found critical to industrialization and modernization for this group. Owning to the differences, Pagell et al. (2005) suggested that each individual country maintains a unique set of characteristics that will affect decisions made within the firm. This notion was also supported by Avittathur and Swimdass (2006) that the supply chain environment in developing countries, such as, India, China and Thailand may not be similar to the environment in the developed nation, US, which may result in different operation and management.

In this research, the multidimensional scaling method (MDS) is adopted to help understanding people's judgment on similarity of members from a set of objects. In other words, the application of MDS, herein, is to recognize the judgment of respondents toward 20 items of LSC, indicating how items relate between each others. Furthermore, MDS was applied to locate position of each category in the individual space. It is a set of data analysis technique that displays the structure of distance-like data as a geometrical picture (Young, 2006). To elucidate, two similar objects are represented by two points that are close together and two dissimilar objects are represented by two points that are far apart. From the literature review in combination with the concept of MDS, the second hypothesis was proposed.

<u>Hypothesis 2</u>*: The positions of companies from developed and developing countries are dissimilar.*

With regards to the differences on ownership status, previous literature defined Multinational and Local, Joint Venture, State Owned Enterprises, etc. to be heterogeneous in organization capabilities, market orientations, strategic objectives and institutional supports (Luo and Tan, 1998). In addition, it was supported by Closs and Molenkopf (2004) that firms in different operating surroundings suggested different capabilities to improve their performance. This heterogeneity may induce different ways of thinking between those societies, which could be seen as dissociated position in the individual space.

<u>Hypothesis 3</u>*: The positions of companies with different ownership status are dissimilar.*

These hypotheses are verified by comparing supply chain operational performance of Japan, Thailand and China. Twenty items in four areas of assessment namely, (1) corporate strategy and inter-organization alignment, (2) planning and execution capability, (3) Logistics performance, and (4) IT methods and implementation were thoroughly evaluated among each participants in the three countries. The strengths and weaknesses from each country are consecutively revealed. In addition, the multidimensional scaling method (MDS) using PROXSCAL algorithm is employed to stratify location of each classified category. Discussions are later made to elucidate how institutional environment affects the level and position of each category in terms of supply chain operational performance among Japan, Thailand and China.

DATA COLLECTION

SCM Logistics scorecard (LSC) has been utilized as a data collection in this stage. This scorecard has been developed since 2001 by Enkawa Laboratory, Tokyo Institute of Technology in collaboration with Japan Institute of Logistics system (JILTS). The element of LSC and its superiority compared with other scorecards were previously discussed in Yaibuathet et al. (2006). Owing to the generality of the LSC, more than 350 data have been accumulated from Japan with the approval of the companies. Differ from other scorecards, this accumulated database has created a virtuous cycle of data collection and reliability of feedback reports (Suzuki, 2006).

Data collection has been extended to China and Thailand from early 2004 in order to expand LSC research scope to international comparison. Accordingly, the LSC was translated into Chinese and Thai languages. Data collection process has been performed in these countries. Similar data collection technique has been adopted by both Japan and Thailand in cooperation with JILS, Chiang Mai University and JETRO (Thailand). Most of the data was obtained by interviewing the high-levelled manager of the company. A feedback report was, then, sent back to each respective company. On the contrary, Chinese data collection has been conducted in cooperation with Tsinghua University by sending e-mail for survey without providing company feedback report. At the time of writing, the accumulated data from Japan, Thailand, and China are successfully completed for 350, 173 and 205 firms, respectively. The category of participating companies in the three countries is also presented in Table 1.

Table 1. The classification detail of participating companies

	Japan	**Thai**	Thai (MNCs)	Thai (Local)	**China**	China (SOEs)	China (Foreign)	China (Private)	China (0thers)
Food	**39**	**35**	9	26	**8**	1	3	2	2
Electronics	**56**	**31**	25	6	**77**	12	26	24	15
Automotive	**29**	**37**	26	11	**16**	14	0	0	2
Chemistry	**23**	**30**	12	18	**38**	4	11	9	14
Fibre	**19**	**12**	0	12	**4**	0	1	2	1
Pharmaceutical	**27**	**8**	2	6	**1**	1	0	0	0
Others	**157**	**20**	6	14	**61**	1	27	10	23
Total	***350***	***173***	***80***	***93***	***205***	***33***	***68***	***47***	***57***

CROSS COUNTRY ANALYSIS

The purpose of this section is to corroborate Hypothesis 1 that supply chain operational performance level between Japan, Thailand and China is different owing to the distinctive institutional environment. In order to investigate domestically differences, the data of Thailand and China was further classified into detailed categories using ownership criteria. Thais were classified into two groups; Multinational (MNC) and Local, whereas Chineses were categorized into four groups; State Owned Enterprises (SOEs), Foreign, Private and others. Althogh more than 350 data was collected from Japanese companies, only 205 data from manufacturing sector was employed in this section. Similarly, only 153 Thai and 200 Chinese manufacturing data was used to compare with the Japanese. The data attribute of overall Japanese, Thai and Chinese manufacturing is presented in Table 2. Tables 3 and 4 display four-area score achieved from the three countries and six categories correspondingly. The reliability analysis of LSC was conducted during the data collection process. The results are shown in terms of Cronbach's coefficient alpha for 20 assessment items at 0.913, 0.928, and 953 from Japan, Thailand, and China, respectively.

Table 2. Data attribute of total score between Japan, Thai and China Manufacturing

	Japan	**Thailand**	**China**
Number of Data	205	153	200
Mean	58.67	57.70	61.53
Standard Deviation	10.74	13.16	16.46
Variance	115.31	173.19	270.99
Median	58	57	62.72
Mode	51	62	79
Range	58.5	61	77
Maximum	87.5	94	100
Minimum	29	33	23

Table 3. The average score of four areas between Japanese and Thai and China (3 country comparison)

	Japan (205)		**Thai (153)**		**China (200)**	
	Ave.	**SD**	**Ave.**	**SD**	**Ave.**	**SD**
1.Corporate strategy and Inter-Organization alignment	3.03	0.63	3.07	0.71	3.37	0.86
2. Planning and Execution capability	2.88	0.62	3.03	0.71	3.01	0.89
3. Logistics Performance	2.78	0.69	2.76	0.74	2.91	0.86
4. IT Methods and Implementation	2.95	0.66	2.68	0.81	2.86	1.01

Table 4. The average score of four areas between Japanese and Thai and China (6 category comparison)

	Jap (205)		**Thai MNCs* (75)**		**Thai Local (78)**		**China SOEs* (33)**		**China F* (68)**		**China P* (47)**	
	Ave	SD	Ave	SD	Ave	SD	Ave	SD	Ave	SD	Ave	SD
1.Corporat strategy and Inter-Organization alignment	3.05	0.63	3.32	0.65	2.82	0.68	3.49	1.00	3.67	0.76	3.26	0.79
2. Planning and Execution capability	2.95	0.57	3.24	0.67	2.82	0.70	3.08	0.96	3.37	0.82	2.90	0.87
3. Logistics Performance	2.76	0.68	3.02	0.77	2.52	0.63	2.95	1.02	3.13	0.80	2.98	0.81
4. IT Methods and Implementation	2.97	0.67	3.03	0.87	2.34	0.53	2.94	1.10	3.22	0.92	2.87	1.00

* MNCs = Multinational Companies, SOEs = State Owned Enterprises, F = Foreign, P = Private

Although the category of Chinese data could be classified into more than three categories (see Clark and Yuxing (1998) for the definition of each category), only three groups of China have been included in this study because these three sectors have contributed to form the economic growth of China over the last 20 years (Clark and Yuxing, 1998). They are China State Owned Enterprises (SOEs), China Foreign (F), and China Private (P).

DISCUSSION-CROSS COUNTRY ANALYSIS
The results achieved from cross country analysis could verify Hypothesis 1, " *The Supply chain operational performance level between Japan Thailand and China is different which may be influenced by different institutional environment*",to some extent especially in Japan and Thailand. However, it was not supported in the case of China. The performance of Japan manufacturing has been possibly influenced by Normative and Cultural-cognitive elements. Thais have been conceivably induced by some of the Normative and Cultural-cognitive factors while Chinese score could be explained by Regulatory and Cultural-cognitive aspects.

JAPAN
The reasons why Japan average scores were lower than expected, may be attributed to some of the Japanese institutions. While some traditions were considered advantageous for Japanese economic extension, some were found to be the main obstacle in upgrading its supply chain operational performance. Considering the *Normative* element, such as, retailers can simply return all unsold goods and avoid the risk of unsold merchandise (JETRO, 1995), this commercial custom has deteriorated the ability of retailer in their goods/ inventory management. The opportunity lost and low inventory turnover have occurred to manufacturer as chain effects of this peculiar custom. It was further observed that this custom appears to have effect on area (3) Logistics performance, since this includes the assessment of inventory turnover and supply chain opportunity cost. Besides, Japanese traditional practice has engaged that the maker is unable to deliver products to the retailer directly, the service of distributor and distribution centre are required. In doing so, the maker has to pay the distribution fee instead of retailers at 2-5 percent of the goods price. The prior examples indicated that retailers gain the highest benefits among the supply chain and they have been indulged too much by the makers. These *Normative elements* or business behaviours could harm the supply chain operational performance of the Japanese company.

Additionally, Japanese persons have a tendency to evaluate themselves rather modestly or strictly. This may come from the typical *culture-cognitive* of high uncertainty avoidance and low individualism of Japanese, which were observed by Hofstede (2005). Furthermore, it was revealed by Takada (2003) and Kitayama and Uchida (2003) that Japanese people tend to be self-critical or rate themselves negatively when the rating is under competition free situation and it was conducted in the context of close, interdependent social relation. Since the Japanese respondents were told that the LSC evaluation is contributed for academic research and their results will be kept secret, the modestly rating may possibly be tracked down among Japanese.

THAILAND
From the finding of Thai industry, two groups are classified, which are Thai Multinational and Thai Local Companies. It was noticed that some of the Institutional Environment may affect performance of both sectors. In the case of MNCs, they were found to be located in high score group. The driving force may

derive from high competition within the same company in other parts of the world. Moreover, proper technology and management know-how were transferred from the Mother Company and installed at the company institution which could reduce *Cultural* problems within the firm. This could allow the institution arrangement to be made effortlessly such as new investment and changes of activity sets. As a result, industries in this group perform better than Locals.

In terms of Thai Local companies which were positioned in the lower score group, most of them originated from family business then expanded to a larger scale. Owners have operated their business using primitive management style and were unenthusiastic to strive for better approach to achieve higher productivity. This could be considered as one of the *Normative* problems for Thai local companies. Furthermore, the low level of changed characteristics have been found in this group such as uneasy to approve for the new investment and intricate to change existing business behaviour. Owing to high investment, the modern IT implementation seemed to be excluded from their existing operation. From the elucidated reasons, corporate strategies regarding SCM and IT utilization area have not been improved much in this group.

CHINA

Considering China, Although many institutional environment constrains, such as, fragile regulatory element, cognitive-culture facet, have been found in previous literature on China, those limitations seem to have no effect on the performance level of Chinese manufacturing discovered in this research. Chinese score is relatively higher than those from Japan. It may possibly result from the culture and personality determinants of leniency in self-rating among Chinese. Among the studies of self-evaluation behaviour in China, a modestly rating was observed in several studies among Chinese respondents from Taiwan (Farh and Cheng, 1997) and Hong Kong (Goodstein et al., 1991; Yik et al., 1998) while a leniency rating was found in some studies among mainland Chinese respondents (Yu and Murphy, 1993). In addition, the study of Xie et al. (2006) provided the valuable evidence on the cultural aspect that individualism is a cultural determinant of self-rating leniency. Since many researchers observed that Chinese people have become quite individualistic, as reflected by their preference for individual-based reward allocation (Chen, 1995), tracking down for individual control in the workplace (Xie, 1996), and self-serving perceptions and behaviours (Brockner and Chen, 1996), it could be possible that mainland Chinese will rate themselves higher than their actual performance.

POSITIONING OF COUNTRIES AND OWNERSHIP CATEGORIES

ANALYSIS APPROACH

The multinational scaling analysis (MDS) was applied to the proximity matrices of two classifications. The first group is composed of four categories: Thailand, Japan, China and reference data of Finland. The second group analyses in more detail, containing seven categories, which are Thai Multinational Companies (MNCs), Thai Local, Japan, China State Owned Enterprises (SOEs), China Foreign, China Private and reference data of Finland. Data from Finland is employed as reference information because of its small number of data (22 respondents). The MDS was applied, herein, using PROXSCAL algorithm (SPSS v.14.0). The utilized scaling model is Weight Euclidean of full proximities matrices, proximities transformations is interval with two dimension solution. Since the data was achieved from four different countries, the Weight Euclidean Model is suitable for these sets of analysis because this model is fit for describing variation in the structure across occasions, setting and treatment conditions (Davision, 1983 p.121)

The interpretation was on the basis of the visual inspection of the MDS configuration. Figure 2 and 3 display the plots of normalized raw stress and the Tucker's coefficient of congruence for the different dimensional solutions. The figures show slight elbows at n=2 dimension, supporting two-dimensional solution for both four countries and seven categories analysis. The stress is considered satisfactory when the value approaches zero which indicates a good fit to the data. However, it is good at 0.05, acceptable at 0.10, and poor from 0.20 on (Kruskal and Wish, 1978). On the contrary, the Tucker's Coefficient of Congruence is acceptable when the value is above 0.90.

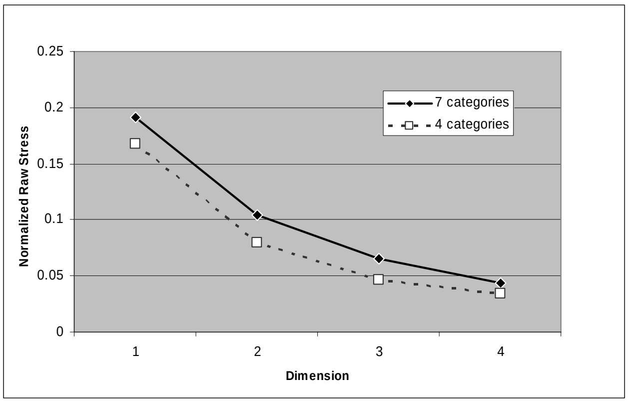

Figure 2 *Stress* in function of the number of dimensions for group structure

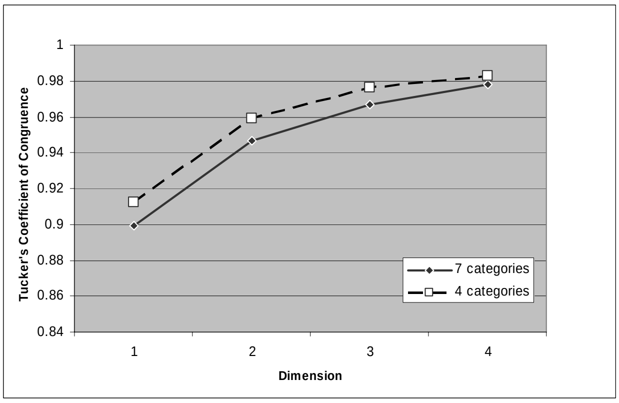

Figure 3 Tucker's Coefficient of Congruence in function of the number of dimensions for group structure

COUNTRY ANALYSIS

The country analysis using MDS is conducted to validate Hypothesis 2 that "t*he position of company from developed country and developing country is disparity".* As a consequence of this method using PROXSCAL algorithm, the final coordination of 20 items from the proximities matrices of 4 countries is shown in Table 5. In addition, the individual space of four countries is plotted in two-dimensional axis which is presented in Figure 4. In this study, data from Finland is also included as reference information for the analysis.

From the result, two dimensions were extracted from MDS solution. The first dimension was referred to as *"Performance Driver Dimension"* as represented on X-axis in Figure 4, whereas Y-axis corresponded to "Performance Dimension". It was clearly observed that the positions of four countries are divided into two groups. The first group includes Japan and Finland signifying the area of developed country whereas the second group contains Thai and China representing the area of newly industrialized developing country. The MDS solution could represent respondent's rating of relationship between items. It could further reflect that the way of thinking between respondents from developed and developing countries are discrepancy. This finding appears to support Hypothesis 2.

Table 5. Final coordination of 20 assessment items – 4 countries analysis

Assessment Item	Dimension 1	Dimension 2
1-(1)Corporate strategy regarding logistics and its importance	0.1254	-1.1663
1-(2) Definition of supplier contract terms & degree of information sharing	-0.6738	-1.0476
1-(3) Definition of customer contract terms & degree of information sharing	-1.2391	-1.3803
1-(4) System for measurement and improvement of customer satisfaction	-1.4129	-0.3805
1-(5) System for employee training and evaluation	-1.1809	0.7043
2-(1) Strategies for optimizing logistics system resources based on design for logistics	0.3666	-0.0703
2-(2) Understanding of market trends & accuracy of demand forecasting	-1.0081	-0.4412
2-(3) Accuracy and adaptability of SCM planning	-1.0054	0.2423
2-(4) Control and tracking of inventory (product/parts/WIP): accuracy and visibility	-0.2336	0.3122
2-(5) Process standardization and visibility	-0.6130	0.5593
3-(1) Just-In-Time	-0.4667	1.3708
3-(2) Inventory turnover & cash-to-cash cycle time	0.3612	1.1519
3-(3) Customer lead time (from order placement to receipt) and load efficiency	0.0634	-0.4047
3-(4) Delivery performance and quality	0.1485	0.5718
3-(5) Supply chain inventory visibility & opportunity costs	0.4345	2.1202
4-(1) Electronic Data Interchange (EDI) coverage	1.6403	0.8247
4-(2) Usage of Bar Coding / Automatic Identification and Data Capture (AIDC)	2.3787	0.4071
4-(3) Effective usage of computers in operations and decision-making	-0.1365	-1.9869
4-(4) Open standards and unique identification codes	1.4211	-1.1284
4-(5) Decision-making systems and support to supply chain partners	1.0301	-0.2584

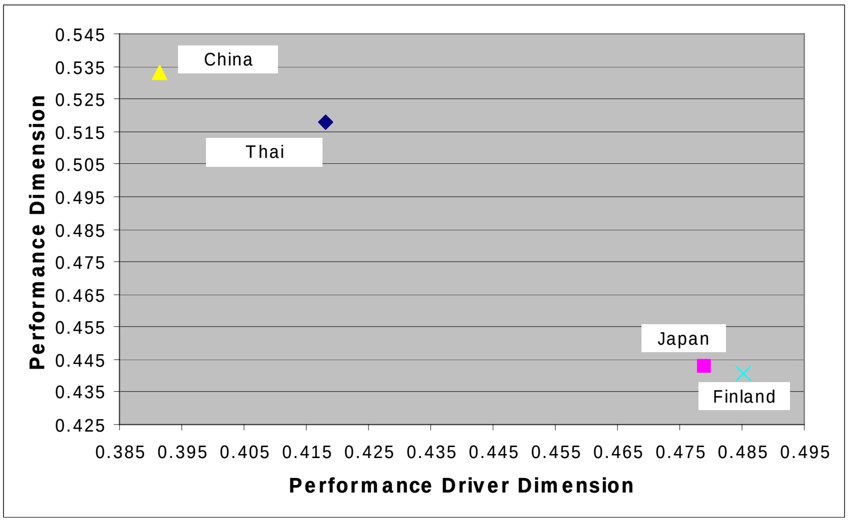

Figure 4. Two dimensional MDS solution – Individual space of 4 countries

COUNTRY AND OWNERSHIP STATUS ANALYSIS

The country and ownership status analysis using MDS is conducted to validate Hypothesis 3. The ownership status is employed as a criterion to categorize companies from Thailand and China. Thais are arranged into two groups, which are Thai Multinational and Thai Local Companies while three groups of China data were employed in this analysis. Furthermore, the data of overall Japan and reference data of Finland is included. Thereby, the proximities matrices of seven categories were utilized as inputs for MDS. The final coordination of 20 items is revealed as a result of MDS as well as the individual space of seven categories. They are respectively shown in Table 6 and Figure 5.

Table 6. Final coordination of 20 assessment items – 7 categories analysis

Assessment Item	Dimension 1	Dimension 2
1-(1)Corporate strategy regarding logistics and its importance	-0.8825	1.0201
1-(2) Definition of supplier contract terms & degree of information sharing	-1.3059	-0.0427
1-(3) Definition of customer contract terms & degree of information sharing	-1.7848	0.1455
1-(4) System for measurement and improvement of customer satisfaction	-0.8446	-1.4677
1-(5) System for employee training and evaluation	-0.8456	0.3798
2-(1) Strategies for optimizing logistics system resources based on design for logistics	-0.0416	0.5198
2-(2) Understanding of market trends & accuracy of demand forecasting	-0.7107	-0.9009
2-(3) Accuracy and adaptability of SCM planning	-0.0124	-1.2786
2-(4) Control and tracking of inventory (product/parts/WIP): accuracy and visibility	0.0341	-0.1219
2-(5) Process standardization and visibility	-0.1430	-0.6400
3-(1) Just-In-Time	1.1085	-0.9522
3-(2) Inventory turnover & cash-to-cash cycle time	0.8228	0.2820
3-(3) Customer lead time (from order placement to receipt) and load efficiency	0.5485	-1.3094
3-(4) Delivery performance and quality	0.6796	-0.3889
3-(5) Supply chain inventory visibility & opportunity costs	1.8476	-0.1939
4-(1) Electronic Data Interchange (EDI) coverage	1.6405	0.8489
4-(2) Usage of Bar Coding / Automatic Identification and Data Capture (AIDC)	0.6345	2.3642
4-(3) Effective usage of computers in operations and decision-making	-1.5687	-0.9013
4-(4) Open standards and unique identification codes	0.8575	1.3820
4-(5) Decision-making systems and support to supply chain partners	-0.0338	1.2552

As a result from 7 categories analysis, the first dimension is similar to the second dimension of 4 countries analysis, denotes "*Performance Dimension*". Whereas the second dimension, herein, is analogous to the first dimension of previous analysis, corresponds to "*Performance Driver Dimension".* To be in line with the result from 4 countries analysis, Performance driver dimension and performance dimension are located on X and Y-axis respectively.

Accordingly, four groups are revealed as a result of two-dimensional analysis. Thai MNCs and China Foreign are located close proximity while China SOEs and China Private appear to have similarity in location. Japan and Finland were in the same group once again in this analysis whereas Thai Local is separated from other groups. The finding, herein, indicates that viewpoints of each group regarding to logistics and supply chain management are different, and it would probably be influenced by ownership status. Thai MNCs and China Foreign may

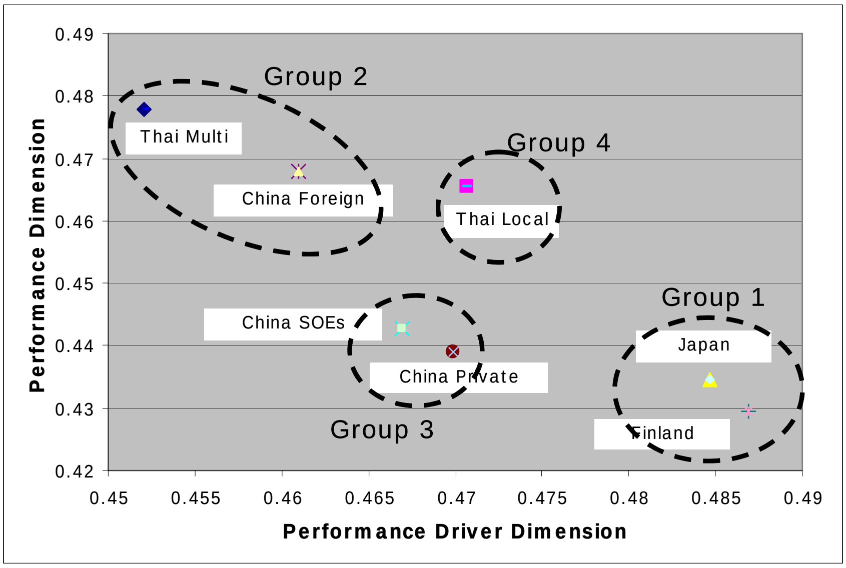

Figure 5. Two dimensional MDS solution – Individual space of 7 categories

be involved with the same investment structure that mainly from overseas. Besides, their management approaches, technology know-how have been imported from Mother Company to support operations in based country. As such, these reasons could support the position homogeneity of Thai MNCs and China Foreign. On the contrary, China Private may be influenced by State owned practices, thus its perspective is relatively similar to the China SOEs. This group could be, again, notified as "*China Local*". Although, the dimension weight of performance driver dimension is found similar, the perception and position of Thai Local and China Local is somewhat different in terms of performance dimension. By contrast, the viewpoints of developed countries in this analysis are discovered not to be similar to any ownership status group. Accordingly, the findings in this section seem to support Hypothesis 3.

CONCLUSIONS AND FUTURE RESEARCH

In general, our findings have empirically verified many conclusions drawn in previous study. From the investigation of supply chain operational performance between the three countries, it was suggested that the institutional environments play important roles in current performance level and could be one of the main hindrance for improving purpose. The strengths and weaknesses in supply chain operation of Japan and Thailand could be explained by the context of institutional environments, which are *Regulative*, *Normative* and *Cultural-cognitive* elements, to some extent. On the contrary, those Institutional Environments seem to have negligible effect on China's performance level. This research further provides results that the way of thinking with respect to SCM from developed and newly industrialized developing countries are incongruent. The underline on firm specific asset reveals that different ownership status gave distinct perspective concerning SCM operation. Nevertheless, none of those groups from developing countries, Thailand and China, has a similar perception to developed country.

More data on three-axis of institutions from the analyzed countries is required to ascertain this fundamental result. Future research can improve upon this research by combining data of (1) National strategy and socio-economic system, (2) Entrepreneurial organization and culture and, (3) Historical perspective aspects of Japan, Thailand and China to conduct more in-depth analysis with LSC data. The result would provide useful insight into 'what typical institutional factors that influence the level of supply chain operational performance in each assessment area and position of business in different environment".

The findings from this research potentially have implications for business sectors in various countries for the purpose of improving supply chain operational performance. Apart from employing proper supply chain innovation such as IT and decision support system, supply chain managers should realistically assess the constraints of Institutional Environment of partners, then adopt suitable institutional arrangement for them so as to develop the SCM and Logistics operations as a whole.

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PARALLEL SCM: BALANCING OF MAKE-OR-BUY AND RETAILER TYPES

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ABSTRACT

It is well known that SCM has the effect that reduces the extra stock and the cost of system, but how it can make all firms to achieve the maximal profit is becoming the new problem. First, the parallel SCM model is identified in this paper, and formulated on the queuing base of Make-or-Buy and Retailer types. Next, the problem of maximizing the profit is discussed in the integral balancing view. The integral balancing means that the both of economics (profit) and reliability (leadtime) hold in balancing. Finally, a feature map in balance matrix is suggested for win-win strategy, and is compared to the ellipse theory in the serial SCM type.

Introduction

In modern society, enterprises are inter-connected each others, and the supply chain forms a flow/value network of enterprises (de Kok and Graves 2003). Then, the win-win problem in supply chain is extended to a world of multiple win-win relations, and also, this problem would be related to an equilibrium/balancing condition of network flow/value in invisible hand.

For this study, we have recently given a fundamental approach in Matsui (2004) by the station-centered approach (Matsui et al, 1977 and Matsui 1982). A few challengeable trial is already seen in Matsui and Ichihara (2003) and Matsui and Motohashi (2006) in two-serial supply chain, and the ellipse theory of SCM is found in balancing. These results give an ideal example of win-win condition in SCM.

However, there may be another problem of win-win in parallel supply chain. This interesting problem is here considered by using two Markovian models. These models are the two simple types of make-to-order and supplier-retailers network systems, and would be better to be treated by a system-centered approach.

This paper discusses a class of integral balancing for win-win strategy in the two parallel models. Integral balancing means that the both of economics (profit) and reliability (leadtime) hold in balancing. A feature map in balance matrix is given for the parallel SCM type, and is compared to the ellipse theory in the serial SCM type.

Two Parallel Models

Production type

The first model consists of two communicated make-to-order enterprises in Figure 1. Suppose that Enterprise 1 is a domestic and high cost shop, while Enterprise 2 is in China and a low cost shop. Also, the profitable orders are accepted at Enterprise 1, and the rejected orders are accepted at Enterprise 2.

Thus, Enterprise 1 decides the make-or-buy action without comeback by a selection criterion (input speed), c, and may have the stock level of backlog, N. Enterprise 2 may have the stock level of backlog, M, and, if the number of backlog is over M, then an arrived order is lost. Enterprise 2 is communicated to Enterprise 1, but both are in non-cooperative relation.

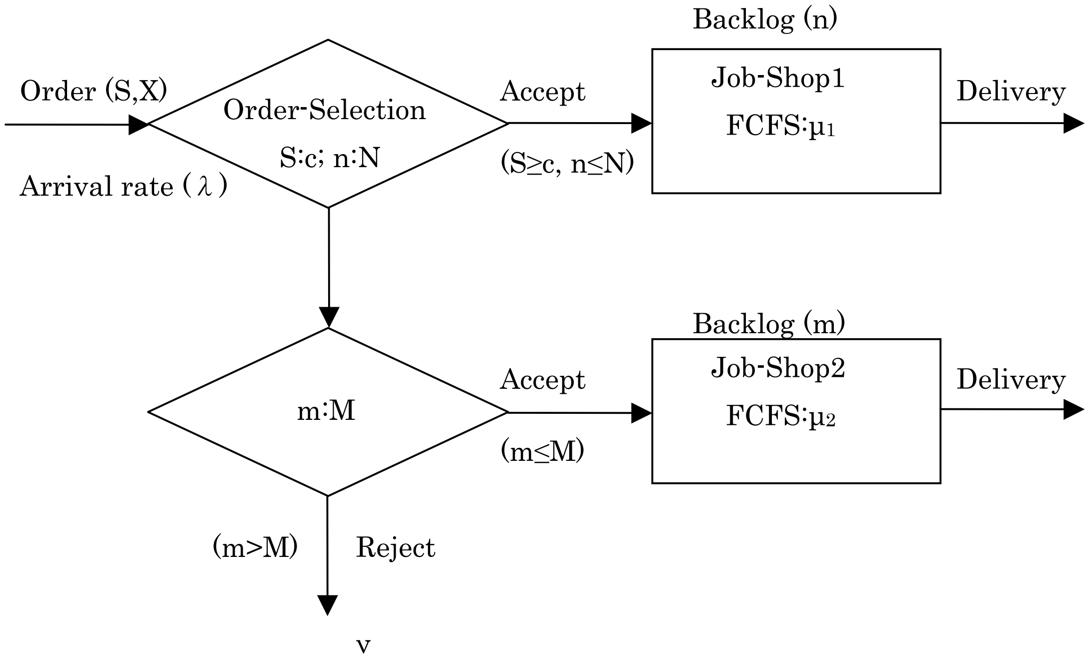

Figure 1 Production type model

The following assumptions and notations are added:

1. The arrival patterns of orders is Poisson distribution with rate λ
2. The marginal profit of orders, S, has an exponential distribution with mean 1.
3. The shops in enterprises are the exponential distribution with rates μ_1 and μ_2, respectively.
4. At Enterprise 1, the arriving orders are screened till the stock level of backlog, N, by selection criterion, c ($0 \leq c \leq \infty$). The rejected orders are removed to Enterprise 2, and are accepted till the stock level of backlog, M. The overflow rate from Enterprise 2, v, is lost.

Sales type

The second model consists of a supplier and two order retailers in Figure 2. The supplier has an infinite capacity, but the two heterogeneous retailers have the stock level of N and M, respectively, in VMI manner. Also, the supplier has a truck with travel time, R, and replenishes the goods (with price p_1) to the retailers at the approximate rate (input speed), λ.

The following assumptions and notations are added:

1. The demand patterns at retailers are Poisson distribution with rates μ_1 and μ_2, respectively.
2. The retailers sell the goods with price p_2. If each stock of retailers are sold out, an arriving customer is lost to the respective retailers.
3. The truck is first routed from the supplier to Retailer 1, and, if it is replenished till stock level, N, it removes to Retailer 2 with negligible delay.
4. The overflow rate from Retailer 2, v, is returned to the supplier.

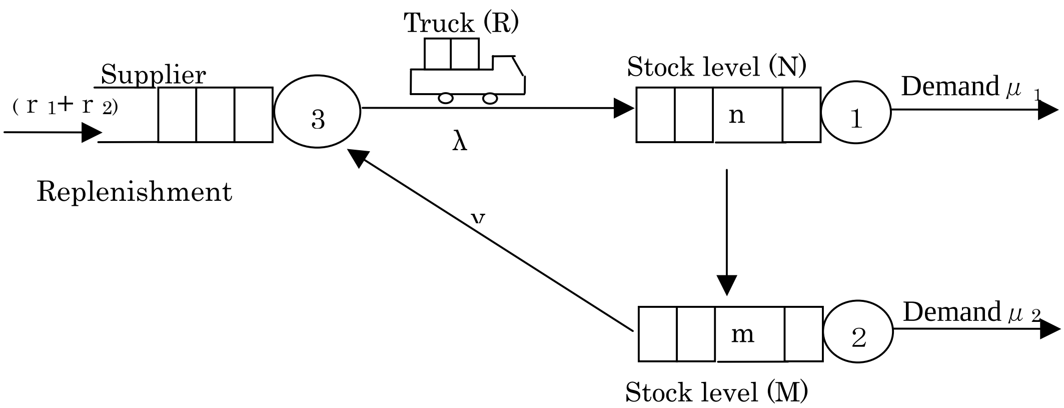

Figure 2 Retailer type model

Also, the goal is the integral balancing of the system. Integral balancing means that both of economics (profit) and reliability (leadtime) hold in balancing.

For economics, the objective criterion is the integral profit:

$$DEN = (ER_1\text{-}EC_1)^+ + (ER_2\text{-}EC_2)^+, \quad (2.1)$$

where ER_i are the revenue per unit time, and EC_i are the operating cost per unit time. If the difference (ER_i- EC_i) is positive, DEN is replaced by MEN.

For reliability, the objective criterion is the mean workload instead of leadtime, and is given by

$$BT = L/\mu, \quad (2.2)$$

where L is the mean number of units, and μ is the processing rate.

Markovian Analysis

Production type

Now, the two type models may be analyzed by a Markovian queuing network. Let us denote the state of the system by a pair (n,m), in which n and m is the number of backlog (goods) in the job-shops (retailers) 1 and 2, respectively. Then, the steady-state probabilities, $\pi(n,m)$, may be given by the system of equilibrium equations.

By using the steady-state probabilities $\pi(n,m)$'s, the objective functions of production type are easily obtained as follows:

$$ER_1 = \lambda(1+c)e^{-c}\sum_{m=0}^{M}\sum_{n=0}^{N-1}\pi(n,m), \quad (3.1)$$

$$ER_2 = \lambda\{\sum_{m=0}^{M-1}\pi(N,m) + (1-e^{-c}-ce^{-c})\sum_{n=0}^{N-1}\sum_{m=0}^{M-1}\pi(n,m)\}, \quad (3.2)$$

$$EC_1 = \alpha_{11}L_1 + \alpha_{21}BP_1 + \alpha_{31}(1-BP_1), \quad (4.1)$$

$$EC_2 = \alpha_{12}L_2 + \alpha_{22}BP_2 + \alpha_{32}(1-BP_2), \quad (4.2)$$

where the busy probabilities, BP_1 and BP_2, are respectively

$$BP_1 = \sum_{n=1}^{N}\sum_{m=0}^{M}\pi(n,m), \tag{5.1}$$

$$BP_2 = \sum_{n=0}^{N}\sum_{m=1}^{M}\pi(n,m), \tag{5.2}$$

and the mean number of backlog, L_1 and L_2, are respectively

$$L_1 = \sum_{m=1}^{M}\sum_{n=0}^{N} n\pi(n,m), \tag{6.1}$$

$$L_2 = \sum_{n=0}^{N}\sum_{m=1}^{M} m\pi(n,m), \tag{6.2}$$

in the job-shops 1 and 2.

In addition, the mean workloads of job-shops, BT_1 and BT_2, are given directly as follows:

$$BT_i = L_i / \mu_i, \qquad i = 1,\ \ 2 \tag{7}$$

These objective criteria are used as the balancing measure of two job-shops instead of reliability.

Sales type

Similar to the section 3.1, the objective functions of sales type are easily obtained by using the steady-state probabilities $\pi(n,m)$'s as follows:

$$ER_i = p_2 r_i, \qquad i = 1,\ \ 2 \tag{8}$$

$$EC_i = \alpha_{0i}K_i + \alpha_{1i}L_i + \alpha_{2i}BP_i + \alpha_{3i}(1 - BP_i), \tag{9}$$

where L_i's and BP_i's are similar to the equations (5) and (6), respectively, and the mean rate of lost sales, LS_1 and LS_2, are given respectively by

$$LS_1 = \sum_{m=0}^{M} \mu_1 \pi(0,m)\,, \tag{10.1}$$

$$LS_2 = \sum_{n=0}^{N} \mu_2 \pi(n,0)\,, \tag{10.2}$$

In addition, the mean workloads of retailers, BT_1 and BT_2, are given directly by

$$BT_i = L_i / r_i, \qquad i = 1,\ \ 2 \tag{11}$$

These objective criteria are used as the balancing measure of two retailers instead of reliability.

For the supplier, the objective functions of reward and cost are given respectively as follows:

$$ER_3 = p_1(r_1 + r_2)\,, \tag{12}$$

$$EC_3 = \beta_1 \upsilon + \beta_2 \lambda R\,, \tag{13}$$

where β_1, β_2 ate cost coefficients, the sales rates, r_1 and r_2, are respectively

$$r_1 = \sum_{m=0}^{M} \sum_{n=1}^{N} \mu_1 \pi(n,m)\,, \tag{14.1}$$

$$r_2 = \sum_{n=0}^{N} \sum_{m=1}^{M} \mu_2 \pi(n,m)\,, \tag{14.2}$$

and the overflow rate from Retailer 2 is as follows:

$$\nu = \lambda - (r_1 + r_2)\,, \tag{15}$$

Balancing Consideration

Production type

For both types, the problem of maximizing the profit is discussed in the integral balancing view. A realization of integral balancing is seen in serial SCM examples (Matsui and Motohashi, 2006). This treatment would be here tried for two type models in parallel SCM, but the problem is not simple.

First, a numerical example is given and considered for production type. This parameter setting is as follows:

$$\lambda = 3.0,\ \mu_1 = 1.0,\ \mu_2 = 2.5$$

$$\alpha_{11} = 0.1,\ \alpha_{12} = 0.1$$

$$\alpha_{21} = 0.4,\ \alpha_{22} = 0.2$$

$$\alpha_{31} = 0.5,\ \alpha_{32} = 0.5$$

In addition, the setting: M=2N is added for simplicity.

Figures 3 and 4 show a balancing example in profit and workload, respectively. However, the integral balancing is not seen in there. The balancing in profit is attainable at c=1.6, but the profit maximization occurs at c=1.2, and the balancing in workload occurs at c=1.4.

These feature map is seen in the balance matrix (c, N) of production type. Table 1 shows partly the ellipse theory of SCM in the meaning that the profit maximization occurs at the ellipse-cross print. However, it is not complete, and the win-win strategy for production type would be variant.

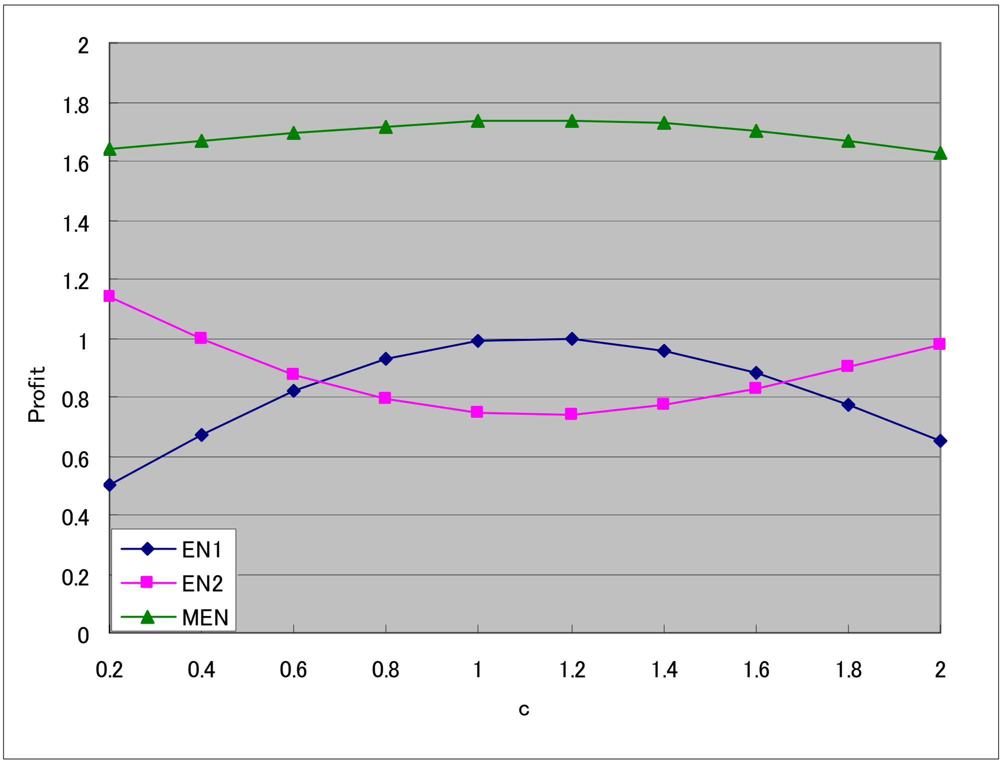

Figure 3 Balancing in profit: λ =3.0, N=3

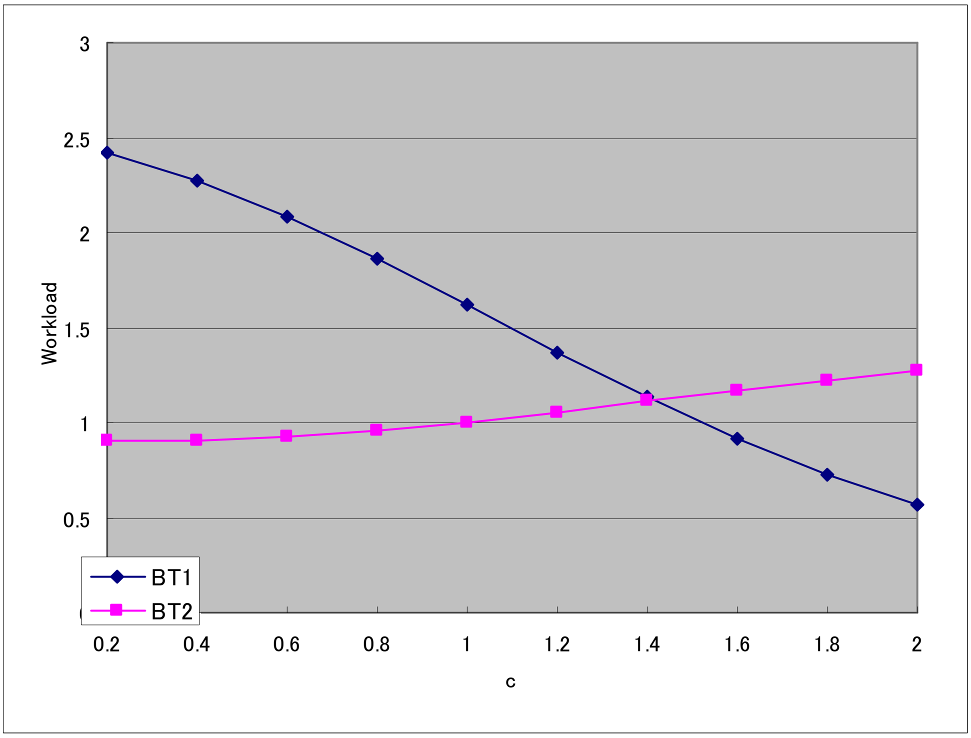

Figure 4 Balancing in workload: λ =3.0, N=3

Table 1　Balance matrix: Production type

c	N		1		2		3		4		5		6	
	EN1	EN2	0.3528	1.0160	0.5100	1.1242	0.5039	1.1376	0.4416	1.1320	0.3573	1.1196	0.2639	1.1043
0.2	BT1	BT2	0.7107	0.3651	1.5304	0.6541	2.4263	0.9025	3.3698	1.1206	4.3407	1.3107	5.3263	1.4740
	EN	BT	1.3688	1.0758	1.6342	2.1845	1.6415	3.3288	1.5736	4.4905	1.4768	5.6515	1.3681	6.8003
	EN1	EN2	0.4350	0.9531	0.6442	1.0129	0.6741	0.9946	0.6357	0.9690	0.5664	0.9445	0.4821	0.9223
0.4	BT1	BT2	0.6679	0.3724	1.4315	0.6662	2.2714	0.9103	3.1676	1.1199	4.1030	1.3011	5.0639	1.4570
	EN	BT	1.3881	1.0403	1.6572	2.0976	1.6687	3.1817	1.6047	4.2875	1.5109	5.4041	1.4044	6.5209
	EN1	EN2	0.4954	0.9082	0.7507	0.9266	0.8186	0.8768	0.8106	0.8282	0.7649	0.7877	0.6981	0.7546
0.6	BT1	BT2	0.6221	0.3798	1.3193	0.6829	2.0832	0.9284	2.9036	1.1313	3.7702	1.3018	4.6732	1.4460
	EN	BT	1.4036	1.0019	1.6773	2.0022	1.6954	3.0115	1.6388	4.0349	1.5526	5.0720	1.4528	6.1192
	EN1	EN2	0.5334	0.8801	0.8242	0.8684	0.9263	0.7921	0.9509	0.7212	0.9351	0.6630	0.8953	0.6163
0.8	BT1	BT2	0.5741	0.3870	1.1962	0.7036	1.8641	0.9591	2.5753	1.1641	3.3265	1.3285	4.1140	1.4608
	EN	BT	1.4134	0.9611	1.6926	1.8998	1.7184	2.8233	1.6721	3.7394	1.5981	4.6549	1.5116	5.5748
	EN1	EN2	0.5493	0.8671	0.8612	0.8392	0.9876	0.7462	1.0389	0.6593	1.0517	0.5865	1.0420	0.5274
1	BT1	BT2	0.5246	0.3938	1.0656	0.7271	1.6229	1.0025	2.1964	1.2248	2.7859	1.4005	3.3913	1.5363
	EN	BT	1.4163	0.9184	1.7004	1.7927	1.7338	2.6254	1.6981	3.4212	1.6382	4.1864	1.5694	4.9276
	EN1	EN2	0.5443	0.8673	0.8612	0.8376	0.9975	0.7403	1.0625	0.6473	1.0928	0.5674	1.1039	0.5008
1.2	BT1	BT2	0.4747	0.4003	0.9325	0.7519	1.3736	1.0553	1.7981	1.3122	2.2061	1.5256	2.5979	1.6994
	EN	BT	1.4116	0.8749	1.6987	1.6844	1.7377	2.4289	1.7098	3.1104	1.6602	3.7318	1.6047	4.2973
	EN1	EN2	0.5205	0.8788	0.8267	0.8599	0.9580	0.7697	1.0223	0.6801	1.0553	0.5999	1.0720	0.5297
1.4	BT1	BT2	0.4252	0.4062	0.8021	0.7767	1.1326	1.1127	1.4197	1.4160	1.6666	1.6887	1.8770	1.9333
	EN	BT	1.3993	0.8314	1.6866	1.5788	1.7277	2.2453	1.7024	2.8357	1.6552	3.3554	1.6017	3.8103
	EN1	EN2	0.4808	0.8993	0.7633	0.9011	0.8784	0.8258	0.9316	0.7447	0.9576	0.6666	0.9705	0.5920
1.6	BT1	BT2	0.3772	0.4117	0.6790	0.8005	0.9140	1.1697	1.0923	1.5223	1.2244	1.8607	1.3203	2.1868
	EN	BT	1.3800	0.7889	1.6644	1.4795	1.7042	2.0837	1.6764	2.6146	1.6242	3.0852	1.5625	3.5071
	EN1	EN2	0.4282	0.9267	0.6784	0.9556	0.7714	0.8985	0.8100	0.8265	0.8267	0.7489	0.8341	0.6676
1.8	BT1	BT2	0.3315	0.4167	0.5671	0.8224	0.7263	1.2224	0.8291	1.6203	0.8931	2.0183	0.9317	2.4173
	EN	BT	1.3549	0.7482	1.6339	1.3895	1.6699	1.9486	1.6365	2.4495	1.5757	2.9115	1.5016	3.3490
	EN1	EN2	0.3663	0.9592	0.5797	1.0180	0.6500	0.9787	0.6753	0.9135	0.6847	0.8343	0.6882	0.7447
2	BT1	BT2	0.2888	0.4212	0.4683	0.8420	0.5718	1.2688	0.6277	1.7048	0.6565	2.1512	0.6708	2.6081
	EN	BT	1.3255	0.7099	1.5977	1.3103	1.6287	1.8406	1.5888	2.3325	1.5190	2.8077	1.4329	3.2789

Sales type

Similar to production type, the integral balancing is considered in sales type. Assume the situation that Retailer 1 is located to neater town than Retailer 2. For this type, a numerical example is given and considered.

The parameter setting is here as follows:

$p_1=1.0, \quad p_2 = 0.9$

$\mu_1 = \mu_2 = 1.2$

$\alpha_{0i} = 0.7, \qquad i = 1,2$

$\alpha_{1i} = 0.03, \qquad i = 1,2$

$\alpha_{3i} = 0.1, \qquad i = 1,2$

$\alpha_{21} = 0.3, \quad \alpha_{22} = 0.2$

$\beta_1 = 0.25, \quad \beta_2 = 0.1,$

$R=1, \quad N+M=8$

Figure 5 shows a balancing example in profit at $\lambda=3.2$ for both supplier and retailers. However, this balancing is except workload and not complete (Figure 6). That is, it is noted that the balancing in profit becomes possible in the situation of high cost in Retailer 1 and high workload in Retailer 2.

These feature map is seen in the balance matrix (λ, N) of sales type (Table 2). From table 2, the ellipse theory of SCM holds in the meaning that the profit maximization occurs at the positioning (3.2, 3), but this is not at the ellipse-cross point, and is a new finding.

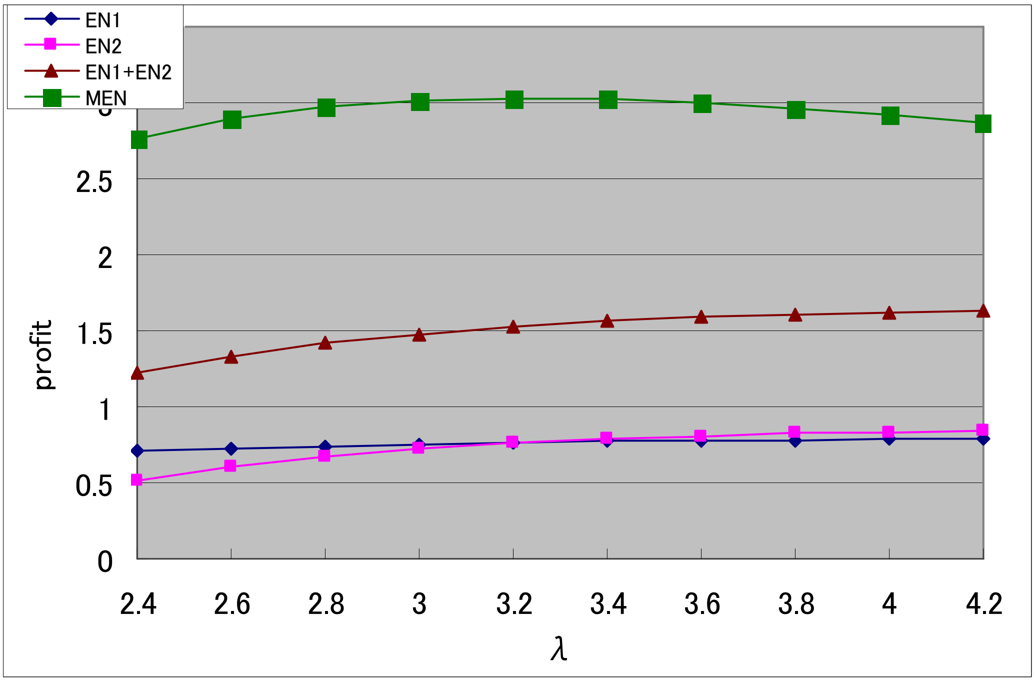

Figure 5　Balancing in profit: N=3, M=5 (MEN=EN_1+EN_2+EN_3)

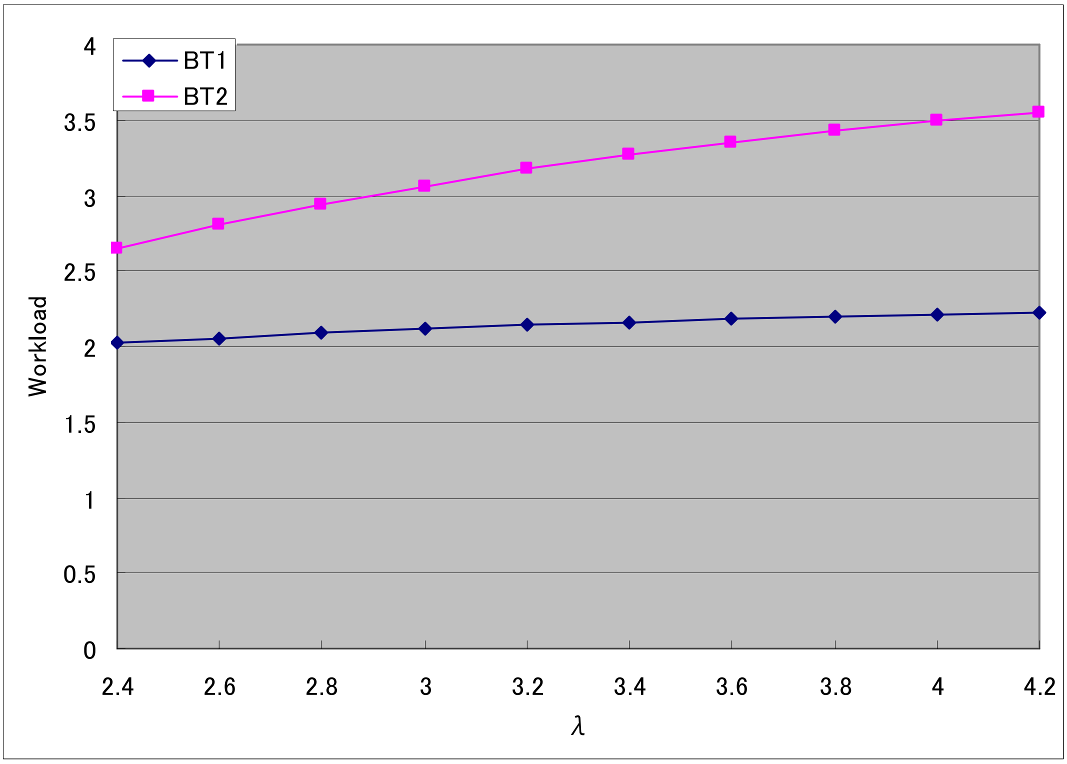

Figure 6　Non-balancing in workload: N=3, M=5

Table 2 Balance matrix: Retailer type

λ	N	1		2		3		4		5		6	
2.4	(EN1, EN2)	0.2667	0.7546	0.5943	0.6310	0.7093	0.5180	0.7458	0.4160	0.7479	0.3026	0.7339	0.1427
	BT1,BT2	0.8333	4.1251	1.3889	3.2060	2.0238	2.6485	2.7222	2.1826	3.4677	1.7328	4.2460	1.2829
	(REN, EN3)	1.0212	1.3853	1.2253	1.5311	1.2273	1.5387	1.1618	1.5008	1.0506	1.4314	0.8765	1.3181
	MEN,BT	2.4066	4.9584	2.7564	4.5949	2.7660	4.6723	2.6626	4.9048	2.4820	5.2005	2.1946	5.5290
2.6	(EN1, EN2)	0.2984	0.7813	0.6218	0.6981	0.7280	0.6073	0.7566	0.5161	0.7530	0.4061	0.7352	0.2415
	BT1,BT2	0.8333	4.3757	1.4035	3.4234	2.0583	2.8026	2.7775	2.2803	3.5415	1.7856	4.3345	1.3029
	(REN, EN3)	1.0797	1.3668	1.3200	1.5388	1.3352	1.5545	1.2727	1.5171	1.1591	1.4446	0.9766	1.3240
	MEN,BT	2.4465	5.2091	2.8587	4.8269	2.8897	4.8609	2.7898	5.0578	2.6037	5.3271	2.3006	5.6375
2.8	(EN1, EN2)	0.3270	0.7963	0.6452	0.7447	0.7427	0.6751	0.7643	0.5962	0.7561	0.4922	0.7354	0.3265
	BT1,BT2	0.8333	4.5807	1.4167	3.6138	2.0886	2.9413	2.8247	2.3695	3.6028	1.8340	4.4062	1.3214
	(REN, EN3)	1.1233	1.3358	1.3899	1.5273	1.4177	1.5509	1.3605	1.5160	1.2482	1.4432	1.0619	1.3187
	MEN,BT	2.4591	5.4140	2.9173	5.0304	2.9687	5.0299	2.8766	5.1942	2.6914	5.4368	2.3806	5.7276
3	(EN1, EN2)	0.3529	0.8042	0.6651	0.7763	0.7543	0.7255	0.7699	0.6594	0.7579	0.5632	0.7351	0.3996
	BT1,BT2	0.8333	4.7473	1.4286	3.7780	2.1154	3.0649	2.8654	2.4502	3.6542	1.8785	4.4650	1.3384
	(REN, EN3)	1.1570	1.2963	1.4414	1.5014	1.4799	1.5318	1.4293	1.5005	1.3211	1.4294	1.1347	1.3038
	MEN,BT	2.4533	5.5806	2.9428	5.2065	3.0117	5.1803	2.9299	5.3156	2.7506	5.5327	2.4385	5.8034
3.2	(EN1, EN2)	0.3764	0.8080	0.6823	0.7972	0.7637	0.7626	0.7740	0.7089	0.7589	0.6217	0.7346	0.4624
	BT1,BT2	0.8333	4.8828	1.4394	3.9184	2.1392	3.1740	2.9006	2.5230	3.6978	1.9191	4.5139	1.3542
	(REN, EN3)	1.1844	1.2510	1.4795	1.4646	1.5263	1.5005	1.4829	1.4733	1.3806	1.4055	1.1970	1.2809
	MEN,BT	2.4353	5.7162	2.9441	5.3578	3.0268	5.3132	2.9562	5.4235	2.7861	5.6169	2.4778	5.8681
3.4	(EN1, EN2)	0.3978	0.8095	0.6971	0.8110	0.7713	0.7895	0.7770	0.7474	0.7595	0.6696	0.7339	0.5163
	BT1,BT2	0.8333	4.9937	1.4493	4.0381	2.1604	3.2699	2.9313	2.5883	3.7351	1.9561	4.5551	1.3687
	(REN, EN3)	1.2074	1.2016	1.5080	1.4201	1.5608	1.4599	1.5243	1.4369	1.4291	1.3732	1.2502	1.2512
	MEN,BT	2.4090	5.8270	2.9281	5.4873	3.0207	5.4303	2.9612	5.5196	2.8023	5.6912	2.5015	5.9239
3.6	(EN1, EN2)	0.4175	0.8098	0.7100	0.8198	0.7775	0.8090	0.7792	0.7772	0.7597	0.7089	0.7332	0.5628
	BT1,BT2	0.8333	5.0850	1.4583	4.1398	2.1795	3.3538	2.9583	2.6468	3.7672	1.9900	4.5902	1.3822
	(REN, EN3)	1.2273	1.1494	1.5298	1.3698	1.5865	1.4122	1.5564	1.3932	1.4686	1.3341	1.2960	1.2159
	MEN,BT	2.3766	5.9183	2.8996	5.5982	2.9988	5.5333	2.9496	5.6052	2.8027	5.7572	2.5119	5.9724
3.8	(EN1, EN2)	0.4356	0.8093	0.7213	0.8254	0.7826	0.8231	0.7808	0.8004	0.7597	0.7412	0.7325	0.6029
	BT1,BT2	0.8333	5.1609	1.4667	4.2265	2.1967	3.4273	2.9822	2.6992	3.7952	2.0209	4.6203	1.3947
	(REN, EN3)	1.2449	1.0950	1.5467	1.3154	1.6057	1.3593	1.5812	1.3439	1.5009	1.2895	1.3355	1.1758
	MEN,BT	2.3399	5.9942	2.8621	5.6932	2.9651	5.6239	2.9251	5.6814	2.7904	5.8160	2.5113	6.0151

Conclusions

This paper shows that the integral balancing does not necessarily hold and be non-complete in parallel SCM. Probably, the win-win strategy for parallel SCM would be not unique and alternative.

The further search should be tried for parallel SCM in integral balancing view. We would hope the development of multiple win-win problem in complex supply chains. The invisible hand in SCM is not simple and may be faced to Braess' paradox (Braess, 1968).

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SUPPLY CHAIN COORDINATION WITH PARTIAL REVENUE SHARING POLICY AND PARTIAL BUY BACK POLICY

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ABSTRACT

One of the major concerns in supply chain management is the coordination among various members of a supply chain comprising manufacturers, distributors, wholesalers and retailers. There are various contracts to coordinate the supply chain. Among others, buyback contracts, revenue-sharing contracts, quantity-discount contracts are well known. So far, however, their effects on the supply chain coordination are discussed separately. In this paper, we investigate the effect of combining buyback and revenue-sharing contracts on the supply chain coordination in a newsvendor problem in which there are one supplier and one retailer. To illustrate the main results, we shall provide a numerical example.

INTRODUCTION

The standard newsvendor problem is concerned with determining the order quantity that maximizes the retailer's expected profit in a single-period, probabilistic-demand setting. In this paper, the newsvendor problem is considered in a single supplier-retailer channel, and the effects of transitioning from a traditional ordering policy to a new policy (a revenue-sharing policy, a buy-back policy and quantity-discounted policy and so on) that is designed to fully coordinate the channel are studied. In a traditional ordering policy, the supplier produces the item at a unit cost of c and subsequently sells the items to the retailer at a wholesale unit transfer price of w, where $w \geq c$. Given transfer price, the retailer determines a locally optimal order quantity Q_T before the actual demand is realized and then sells the items to the end consumers at a predetermined fixed retail unit price of p, where $p \geq w$. Because $w \geq c$, $Q_T \leq Q^*$ as well, where Q^* is the fully integrated (coordinated) channel optimal order quantity(The superscript "*" is used throughout the paper to indicate specific parameter values that correspond to Q^*.). Full channel integration is achieved when the supplier also acts as the retailer, or equivalently, when $w = c$ (in that case, $Q_T = Q^*$). Because $Q_T \leq Q^*$, there is double marginalization in the channel in that the combined profits of the supplier and the retailer do not reach the full profit potential of a fully coordinated channel.

The resolution to the problem is the policy based on contracts. It is a technique for acquiring the maximum expected profit in supply chain based on the standard newsvendor problem consisting of one supplier and one retailer. Therefore, double marginalization can be completely eliminated in this case.

Under reasonable assumptions ($p \geq w \geq c > 0, r \geq b > 0$), the coordination of each member's expected profit is limited to some extent. The answer dealing with the problem is to perform plural contracts.

On the other hand, in the previous works, it is common to hedge the 100% risk. However, in reality, it can't hedge the 100% risk, but it can hedge the risk in some extent. Here, we call the former FULL and the latter PARTIAL.

In this paper, we focus on a discussion on PARTIAL policy. This research differs from previous works on similar policies in two aspects: first, by setting the transfer price at r and the buy-back price b, the proposed policy is designed to completely eliminate double marginalization instead of partially integrating the channel; second, by setting parameters except contract parameters, we show that each member's expected profit is expressed in the entire region. This implies the fairness of the members' expected profit.

The possibility of using revenue sharing as a means of mitigating double marginalization in a channel has been long recognized. The video-rental industry has been identified as an application of newsvendor-based models because demand for "new releases" is short-lived and can be reasonably approximated by the single-period newsvendor model.

A comprehensive revenue-sharing policy in a newsvendor setting was studied by Dana and Spier(2001) and Christos K,.(2006), who consider a single-period newsvendor model and a revenue-sharing policy in the video-rental industry with multiple competing retailers. Their works show that in order to achieve full channel coordination, the unit transfer price r should be equal to zero and the supplier should receive 100% of the revenue. They also state that it is still possible to achieve full channel coordination when $r > 0$, provided that the revenue share of the supplier is computed according to an appropriate formula. The proposed model differs from the Dana and Spier(2001) model in two aspects: first, because of the fixed retail price assumption, the proposed model does not consider multiple retailers who may engage in price competition; second, in their model, the effect of transitioning from a traditional ordering policy to a revenue-sharing policy is studied separately for each party in the channel. That is, they focus on the effect of the revenue-sharing policy on the retail price, which is assumed fixed in their model.

Cachon and Lariviere(2001) present a nonanalytical treatment of a revenue-sharing policy similar to the one proposed in this paper. They conclude that revenue sharing will increase channel profits provided that the cost of producing additional units is smaller than the generated incremental revenue and administrative burden associated with revenue sharing is small enough.

Revenue sharing is not the only way to achieve channel coordination. A returns policy, in which the supplier pays the retailer for each unit not sold, can be used to mitigate double marginalization. A converse to a return policy is a channel-rebates policy, in which the supplier pays the retailer on the basis of the number of units sold. A variant of rebate policies is quantity-discount policies, in which the discount is based on the quantity that the retailer purchases from the supplier rather than on actual retailer sales. A summary of the literature on the above policies is also presented in **Table 1**.

Table 1. A summary of the related literature

Policy	References
Revenue sharing	Pasternack(2001), Dana and Spier(2001), Cachon and Lariviere(2001)
Consignment	Mishra and Raghunathan(2004)
Returns	Pasternack(1985), Donohue(2000), Taylor(2001), Tsay(1999), Padmanabhan and Png(1997), Emmons and Gilbert(1998), Webster and Weng(2000)
Rebates	Taylor(2002)
Quantity discounts	Jucker and Rosenblatt(1985), Pantumsinchai and Knowles(1991), Khouja(1996), Chen, Federgruen and Zheng(2001), Weng(1995)

In this paper, we consider the supply chain coordination with partial revenue-sharing policy and buy-back policy at the same time. We formulate our model and solve the problem. Moreover, we provide numerical examples to illustrate our model.

THE TRADITIONAL MODEL

Consider a single-item newsvendor problem with nonnegative, continuous demand function denoted by $X \geq 0$; let f be the probability density function of X, $F(y) = \int_0^y f(x)dx$ be the cumulative distribution function of X, and $G(y) = \int_0^y xf(x)dx$ be the truncated expected value function. Under the traditional ordering policy, the optimal order quantity for the retailer Q_T is determined as the solution of the equation

$$F(Q_T) = \frac{p-w}{p}, \tag{1}$$

and the expected profit for the retailer $EPR(Q_T)$ can be computed as

$$\begin{aligned} EPR(Q_T) &= (p-w)\int_0^{Q_T} xf(x)dx - w\int_0^{Q_T}(Q_T - x)f(x)dx + (p-w)Q_T\int_{Q_T}^{\infty} f(x)dx \\ &= p\{G(Q_T) - Q_T F(Q_T)\} + (p-w)Q_T. \end{aligned} \tag{2}$$

The combination of (1) and (2) yields

$$EPR(Q_T) = pG(Q_T) = (p-w)\frac{G(Q_T)}{F(Q_T)} . \tag{3}$$

It is obvious from (1) that the retailer is willing to stock additional units as long as w decreases. The supplier's profit $MP(Q_T)$ does not depend on the actual sales volume and is given as

$$MP(Q_T) = (w-c)Q_T . \tag{4}$$

Under this traditional ordering policy, the supplier may act as a Stackelberg leader and unilaterally set w at the level r_s which maximizes the supplier's profit subject to retailer acceptance. The r_s value and the corresponding retailer optimal order quantity Q_s are derived by Lariviere and Porteus(2001). Since it follows that $r_s > c, Q_s < Q^*$. There is double marginalization in the channel in the Stackelberg leader case. This double marginalization cannot be completely eliminated under a traditional ordering policy unless $r_T = c$ in which case the supplier's profit will be equal to zero. By contrast, our proposed partial revenue sharing and partial buy back policy is designed to induce the retailer to order the fully integrated channel optimal order quantity Q^*, which can be computed as the solution of the equation

$$F(Q^*) = \frac{p-c}{p} \left(Q^* = F^{-1}\left(\frac{p-c}{p}\right)\right). \tag{5}$$

THE EXTENSION OF THE TRADITIONAL MODEL

The corresponding wholesale unit transfer price r can be determined as follows. Under the proposed revenue-sharing policy, the retailer pays the supplier a revenue share of $\alpha(w-r)$ per unit actually sold in addition to the unit purchase price r and therefore faces a unit overstocking cost of $p-\alpha(w-r)-r$. The unit under stocking cost is r. On the other hand, under the proposed buy-back policy, the supplier pays the retailer a buy-back of βb per unit actually leftover. Here, we consider the parameters (α,β) to express the fairness of each expected profit. When $\alpha=1$ and $\beta=0$, our policy is consistent with a revenue-sharing policy. When $\alpha=0$ and $\beta=1$, our policy is consistent with a buy-back policy.

The retailer's expected profit "$\Pi_r(Q)$" is given as

$$\Pi_r(Q) = \int_0^Q (px-rQ)f(x)dx - \int_0^Q \alpha(w-r)xf(x)dx + \int_0^Q \beta b(Q-x)f(x)dx$$
$$+\int_Q^\infty (p-r)Qf(x)dx - \int_Q^\infty \alpha(w-r)Qf(x)dx\,. \tag{6}$$

Our objective is to examine the property of the objective function. Taking the first derivative of $\Pi_r(Q)$ with respect to Q yields

$$\frac{\partial \Pi_r(Q)}{\partial Q} = \{-p+\alpha(w-r)+\beta b\}\int_0^Q f(x)dx + p - r - \alpha(w-r)\,,$$

and the second derivative of $\Pi_r(Q)$ with respect to Q yields

$$\frac{\partial^2 \Pi_r(Q)}{\partial Q^2} = \{-p+\alpha(w-r)+\beta b\}f(Q)\,.$$

Here, we consider $\Pi_r(Q)$ is strictly concave. Therefore, as a condition for $\Pi_r(Q)$ to be a concave function, the derivative of second order must be negative, that is $p>\alpha(w-r)+\beta b$. From $\frac{\partial \Pi_r(Q)}{\partial Q}=0$, we obtain

$$F(Q) = \frac{p-r-\alpha(w-r)}{p-\alpha(w-r)-\beta b}\,. \tag{7}$$

From equations (5) and (7), we have

$$\frac{p-r-\alpha(w-r)}{p-\alpha(w-r)-\beta b} = \frac{p-c}{p}\,. \tag{8}$$

Thus, our policy can be completely eliminated double marginalization.

On the other hand, the supplier's expected profit "$\Pi_s(Q)$" is given as

$$\Pi_s(Q) = (r-c)Q + \int_0^Q \alpha(w-r)xf(x)dx - \int_0^Q \beta b(Q-x)f(x)dx + \int_Q^\infty \alpha(w-r)Qf(x)dx\,. \tag{9}$$

Here, if we substitute r' for $r-\beta b$ and w' for $\alpha w+(1-\alpha)r$ in our model, our model is same form as Christos Koulamas's model. However, as previously mentioned in the introduction, there is a case where p (a sale cost) $\geq w$ (a wholesale cost) $\geq c$ (a unit cost) >0 and/or r (a unit transfer price) $\geq b$ (a unit buy-back cost) aren't satisfied. To deal with this problem, we have to treat plural contracts. We can fully design to express the fairness of the members' expected profit. Thus, we must consider a problem of how to allocate each member's expected profit.

THE PROPOSED MODEL

We consider the problem for maximizing the other expected profit subject to guaranteeing one expected profit in the supply chain members. We propose the mathematical programming program, which is given:

$$\begin{aligned}
\max \quad & \Pi_r(Q^*, b, \alpha, \beta, r) \\
s.t. \quad & \Pi_s(Q^*, b, \alpha, \beta, r) \geq K, \\
& \frac{p - r - \alpha(w - r)}{p - \alpha(w - r) - \beta b} = \frac{p - c}{p}, \\
& p \geq \alpha(w - r) + \beta b, \\
& p \geq w \geq c > 0, \quad r > \beta b.
\end{aligned}$$

This is the problem of maximizing the retailer's expected profit under the condition that the supplier's expected profit is greater than the target value (K). Here, we introduce a Lagrangean multiplier (λ) to solve the problem. Thus, the Lagrangean multiplier function ($L(Q^*, b, \alpha, \beta, r; \lambda)$) is given:

$$L(Q^*, b, \alpha, \beta, r; \lambda) = \Pi_r(Q^*, b, \alpha, \beta, r) - \lambda(\Pi_s(Q^*, b, \alpha, \beta, r) - K) \,. \tag{10}$$

The necessary and sufficient conditions to solve the problem are expressed as:

$$\frac{\partial L(Q^*, b, \alpha, \beta, r; \lambda)}{\partial b} = \beta(1 + \lambda)\int_0^{Q^*} (Q^* - x) f(x) dx \geq 0 \,, \tag{11}$$

$$\frac{\partial L(Q^*, b, \alpha, \beta, r; \lambda)}{\partial r} = (1 + \lambda)\left\{\alpha\left[\int_0^{Q^*} x f(x) dx + \int_{Q^*}^{\infty} Q^* f(x) dx\right] - Q^*\right\} \geq 0 \,, \tag{12}$$

$$\frac{\partial L(Q^*, b, \alpha, \beta, r; \lambda)}{\partial \alpha} = (1 + \lambda)(r - w)\left[\int_0^{Q^*} x f(x) dx + \int_{Q^*}^{\infty} Q^* f(x) dx\right] \geq 0 \,, \tag{13}$$

$$\frac{\partial L(Q^*, b, \alpha, \beta, r; \lambda)}{\partial \beta} = (1 + \lambda)\int_0^{Q^*} b(Q^* - x) f(x) dx \geq 0 \,, \tag{14}$$

$$\lambda\left(\Pi_s(Q^*, b, \alpha, \beta, r) - K\right) = 0 \,, \tag{15}$$

$$\frac{p - r - \alpha(w - r)}{p - \alpha(w - r) - \beta b} = \frac{p - c}{p} \,, \tag{16}$$

$$p \geq \alpha(w - r) + \beta b, \tag{17}$$

$$p \geq w \geq c > 0, \quad r > \beta b \,.$$

Now, differentiating equation (10) with respect to Q^*, we obtain

$$F(Q) = \frac{p - \alpha(w - r) - r - \lambda\{(r - c) + \alpha(w - r)\}}{p - \beta b(1 + \lambda) - \alpha(w - r)(1 + \lambda)} \,.$$

Here, when $\lambda = -1$, the order quantity (Q) equals to $F^{-1}\left(\frac{p - c}{p}\right)$. That is, this value is same value as the optimal order quantity (Q^*). Therefore, when $\lambda = -1$, conditions (11)-(14) are satisfied. On the other hand, we must check if the others ((15)-(17)) are satisfied. Now, we can obtain the optimal parameters

($b^*, \alpha^*, \beta^*, r^*$) by solving b, α, β and r which satisfy these conditions. Here, we propose an algorithm to search for the optimal parameters and each member's expected profit.

[**SOLVING ALGORITHM**]

Step1. Set a specified supplier's expected profit (K).

Step2. As long as $\lambda = -1$, conditions ((11)-(14)) are satisfied. So, we solve b, α, β and r satisfying conditions ((15)-(17)).

Step3. From (6) and (9), we obtain the retailer's expected profit and the supplier's expected profit, respectively. (**END**)

NUMERICAL EXAMPLES

To illustrate the model proposed in the previous chapter, we provide the numerical examples. In our model, we use the following parameter values: $p = 100$, $w = 5$, $c = 3$, $U(0,100)$. Then, the overall optimal ordering quantity (Q^*) is obtained as $Q^* = F^{-1}\left(\dfrac{p-c}{p}\right) = 100 \times \dfrac{10-3}{10} = 70$. Now, we have four parameter values, namely, b, α, β and r. If we decide three values among four, the left one is obtained using Equation (16). For example, if we get $b = 2.857143$, $\alpha = 0.9$ and $\beta = 0.1$, then $r = 1.986301$. The ordering quantity (Q^*) is obtained as $Q^* = 70$, it becomes the optimal ordering quantity of unified channel. As for each member's expected profit in the supply chain, we get the retailer's expected profit $\Pi_r(Q^*) = 199.5479$ and the supplier's expected profit $\Pi_s(Q^*) = 45.45205$. The total expected profit is 245. And **Figure 1** shows each member's expected profit when $\alpha = 0.9$, $\beta = 0.1$ and $b = 2.857143$.

Next, we provide the change of each number's expected profit when α is altered from $\alpha = 0.1$ to $\alpha = 1.0$. As shown in **Table 2**, if we raise the value of α, the retailer's expected profit is decreased. Conversely, the supplier's expected profit is increased. Here, there exist many combinations (b, α, β, r) that satisfy Equation (16). Therefore, we consider the mathematical problem we formulated in the previous chapter. For example, we deal with the problem of maximizing the retailer's expected profit subject to the supplier's minimum expected profit, that is, $K = 100$. In this case, we get the retailer's expected profit $\Pi_r(Q^*) = 145$ and Lagrangean multiplier $\lambda = -1$, which satisfy Equations (11) through (14). Therefore, we can get the optimal parameter values (b^*, α^*, β^*, r^*) which satisfy Equations (15) through (17). Namely, $b^* = 0.771$, $\alpha^* = 1.251$, $\beta^* = -0.251$ and $r^* = 1.582$. The results are shown in **Table 3**.

Now, setting $r' = r - \beta b = 1.776$ and $w' = \alpha w + (1-\alpha) r = 5.857$, we can express the same form as the revenue sharing policy. They satisfy $p = 10 > w' = 5.857 > c = 3 > 0$.

On the other hand, we investigate the problem of maximizing the retailer's expected profit subject to the supplier's minimum expected profit $K = -20$. In this case, we get the retailer's optimal profit $\Pi_r(Q^*) = 265$ and the optimal Lagrangean multiplier $\lambda = -1$. We can obtain the optimal parameter values (b^*, α^*, β^*, r^*) which satisfy Equations (15) through (17). That is, $b^* = 0.091$, $\alpha^* = -0.597$, $\beta^* = 1.597$ and $r^* = 3.390$. The results are shown in **Table 4**. From the example shown in **Table 4**, we can see that $r' = 3.246$ and $w' = 2.429$, which do not satisfy $p > w' > c > 0$.

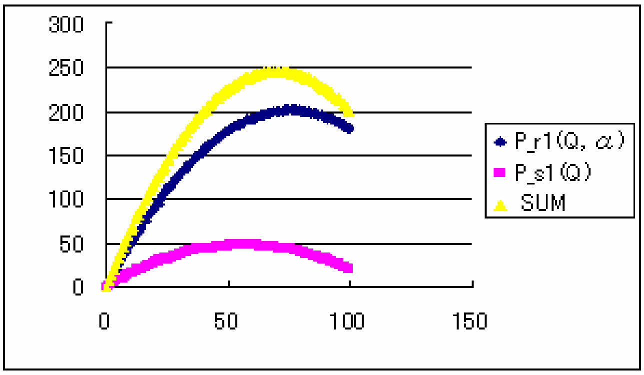

Figure 1. Each member's expected profit and the total expected profit when $\alpha = 0.9$, $\beta = 0.1$ and $b = 2.857143$.

Table 2. Each member's expected profit when α is altered

α	$\Pi_r(Q^*)$	$\Pi_s(Q^*)$	SUM
0.0	455	-210	245
0.1	424	-179	245
0.2	396	-149	245
0.3	364	-119	245
0.4	335	-90	245
0.5	306	-61	245
0.6	278	-33	245
0.7	251	-6	245
0.8	225	20	245
0.9	199	46	245
1.0	175	70	245

Table 3. The results of the retailer's maximum expected profit subject to the assurance of the supplier's minimum expected profit ($K = 100$)

α^*	β^*	b^*	r^*	$\Pi_r(Q^*)$
1.251	-0.251	0.771	1.582	145

Table 4. The results of the retailer's maximum expected profit subject to the assurance of the supplier's minimum expected profit ($K = -20$)

α^*	β^*	b^*	r^*	$\Pi_r(Q^*)$
-0.597	1.597	0.091	3.390	265

Thus, if we consider all the situations, we have to take the plural contracts into consideration.

CONCLUDING REMARKS

Recently, the supplier and retailer have implemented a lot of policies to coordinate distribution channels more effectively. For example, there are buy-back policy, revenue-sharing policy, quantity-discount policy and so on. We have considered a standard newsvendor problem in a single manufacturer and retailer with those policies. That is, by adopting traditional ordering policies, all of members in the supply chain can completely eliminated “double marginalization”. However, in traditional models, they introduced the supply chain coordination to generate the optimal ordering quantity by treating only one policy. Consequently, it became a confined distribution of expected profit in the supply chain. But we have shown that each member’s expected profit could be coordinated by treating plural contract policies:partial buy-back policy and revenue-sharing policy. As a result, we could completely eliminate “double marginalization”. Moreover, we could adjust the expected profits of members in the supply chain.

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AN ANALYSIS OF DISASSEMBLY SYSTEMS WITH REVERSE BLOCKING

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ABSTRACT
For sustainable manufacturing, manufacturers should construct and design inverse manufacturing systems consisting of assembly and disassembly systems. The sorting process in the disassembly system is the first process of the inverse manufacturing system, therefore, it can become a bottleneck and decrease the productivity of the whole inverse manufacturing systems.

This study focuses on a disassembly system with reverse blocking in a sorting process (Yamada and Matsui, 2003). It generalizes the queuing model and discusses the performance of the disassembly systems by a mathematical and numerical analysis.

First, the sorting process with the reverse blocking is generally modeled as a queuing system. Next, the stationary state equations of the system are formulated, and the objective function is set as the throughput. Finally, the system performance is discussed by using a mathematical and numerical analysis in cases of a different number of stations and buffers.

KEYWORDS
reverse blocking, sorting process, inverse manufacturing, queuing analysis, recycling and reuse, sustainable manufacturing

INTRODUCTION
For sustainable manufacturing (Seliger et al., 2006), manufacturers need to consider the environmental-conscious manufacturing (Aksoy and Gupta, 2005) and product life cycle including recycling and reuse. These considerations require construction and design of efficient inverse manufacturing systems (Chiyokura and Aihara, 1999; Kuriyama, 2001), which consists of assembly and disassembly systems. The disassembly systems mainly have sorting and disassembly processes.

In the sorting process, used and collected products from users first arrive at a sorting station, they are serviced and then the product types are identified, and sorted into each type and sent to the appropriate different succeeding stations.

The sequences and mixed ratio of input products types at the sorting station are unknown because they are used products. When the same type products intensively arrive at a particular succeeding station, the limited buffer capacity is full at the succeeding station. Then, the preceding sorting station is blocked if the next product of the same type is serviced at the sorting station and sent to the same succeeding station. Also, the other succeeding stations starve and stop during the blocking (Balsamo et al., 2003) though they are available, and this decreases the throughput of the sorting process. The blocking phenomenon does not occur at assembly systems but only disassembly systems, and we find and call it “reverse blocking” (Yamada and Matsui, 2003). Since the sorting process must be set to the first station of the disassembly systems, it can become a bottleneck and decrease the productivity of the entire inverse manufacturing system. Therefore, it is important to analyze and design the throughput of the sorting process.

This study presents a queuing model of the sorting process with reverse blocking (Yamada and Matsui, 2003), analyzes the throughput of the process and discusses the system performance. First, the sorting process with the reverse blocking is generally modeled as a queuing system. Next, the stationary state equations of the system are formulated, and the objective function is set as the throughput. Finally, the system performance is discussed by using a mathematical and numerical analysis in cases of a different number of stations and buffers.

EXPLANATION OF MODEL

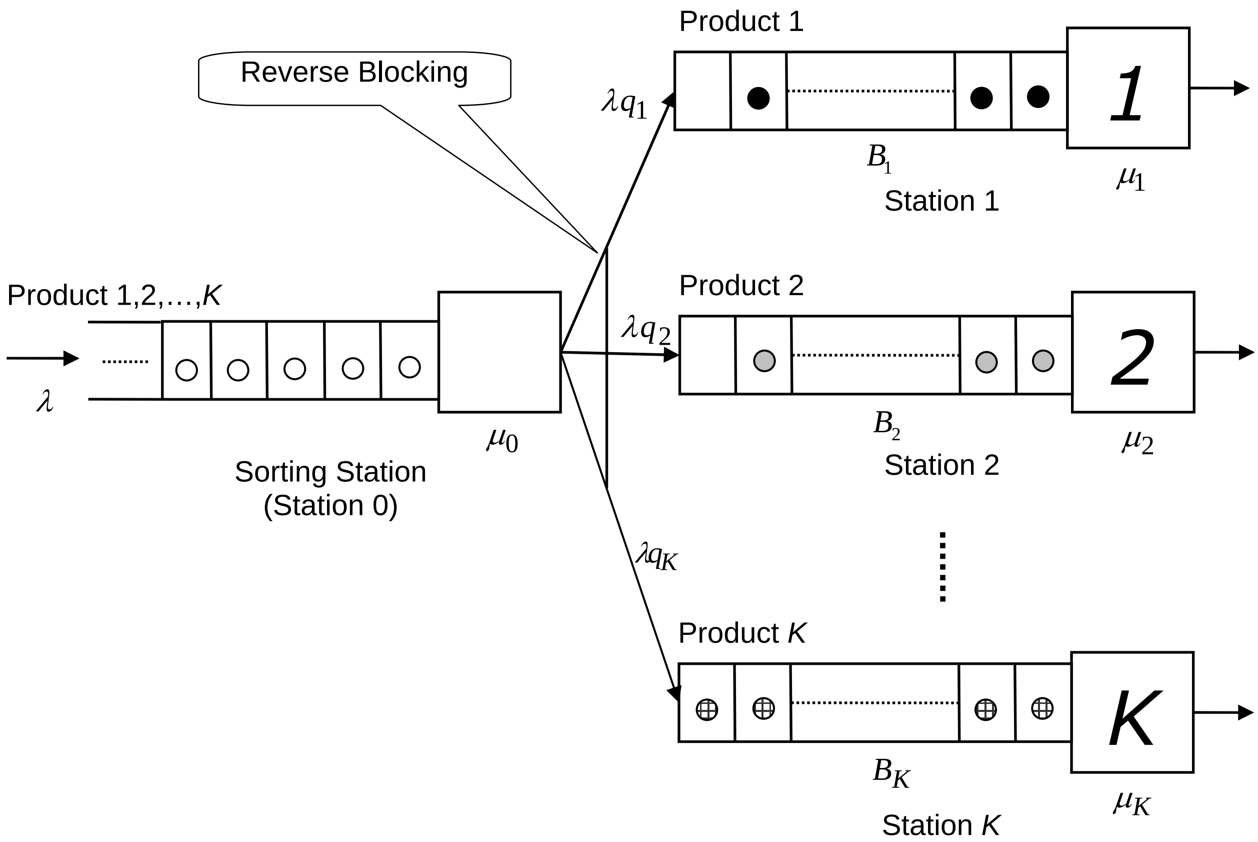

Fig. 1 A queuing model of the sorting process with reverse blocking

This study deals with the sorting process in a disassembly system (Chiyokura and Aihara, 1999; Kuriyama, 2001). The sorting process consists of one sorting station and the K succeeding processing stations. The collected products from users are first arrive at the sorting station. The input product types and the mixed ratio (routing probability to each succeeding station) are unknown because they are used products. After being processed at the sorting station, the product types are then identified. After that, they are sorted into each type of producs and sent to the different succeeding stations according to the product type.

Fig. 1 shows a queuing model of the sorting process with the reverse blocking. It is assumed that products arrive at the sorting station with mean arrival rate, λ. There are K types of products, and the mixed ratio (routing probability) for product i (to station i) is set as q_i. The buffer capacity at the sorting station (station 0), is infinity and no starvation. The mean arrival rate, mean service rate and finite buffer capacity at each succeeding station are set as λq_i, μ_i and B_i at station i ($i=1, 2, \ldots, K$), respectively.

When the same type products intensively arrive at a particular succeeding station, the buffer capacity at the station is full because of limited capacity. Then, the preceding sorting station is blocked if the next product of the same type is processed at the sorting station and sent to the same succeeding station. Its blocking type is BAS (blocking after service) (Balsamo et al, 2003). Also, the other succeeding station sometimes starves and stops because of the blocking. This phenomenon is called reverse blocking (Yamada and Matsui, 2003).

A summary of the notation used in this paper is given below:

i	:	number of stations ($i = 0,1,2, \ldots, K$)
λ	:	mean arrival rate at system
μ_i	:	mean service rate at station i ($i = 0,1,2, \ldots, K$)
B_i	:	buffer capacity at station i ($i = 1,2, \ldots, K$)
q_i	:	routing probability to station i where $\sum_{i=1}^{K} q_i = 1$
ρ_i	:	utilization rate at station i
l_i	:	number of in-process inventories at station i (buffer + service)
BL_i	:	reverse blocking probability at station i
BL	:	total reverse blocking probability at system
TH_i	:	throughput at station i
TH	:	throughput at system

The assumptions of the model used in this paper are given below:

1) The system is stationary.
2) Products arrive at the system with mean arrival rate, λ, and are first serviced at the sorting station (station 0).

3) There are infinite products as the in-process inventories and no starvation at the sorting station (station 0).
4) The succeeding stations of the sorting station, i.e., each succeeding station (station *i*), independently follows the exponential service with the mean service rate, μ_i, respectively.
5) The travel time of each product is zero.
6) There is no failure at each station.
7) The buffer capacity at station *i* is B_i ($i = 1, 2, \ldots, K$).
8) The dispatching rule at all stations is FCFS (First Come First Served).
9) $\rho_i = \lambda q_i / \mu_i < 1$.

OBJECTIVE FUNCTION

This study focuses on the number of the in-process inventories at each succeeding station, and it considers the changes of the states for this system (Asadathorn and Chao, 1999; Aksoy and Gupta, 2005). Each state is represented as the number of the in-process inventories at each station, state $(l_1, l_2, \ldots, l_i, \ldots, l_K)$. The reverse blocking occurs as follows:

When the buffer capacity at the succeeding station *i* is full (i.e., the number of in-process inventories, $l_i = B_i + 1$), a new product at the sorting station has just been processed, identified as a type *i* product. However, the type *i* product cannot enter the succeeding station *i* because the buffer capacity at station *i* is already full. Therefore, the product stays at the preceding sorting station, and thus it blocks and stops the sorting station until the service at station *i* is completed and the buffer capacity becomes available. This reverse blocking state is represented as $l_i = B_i + 2$.

Let $P(l_1, l_2, \ldots, l_i, \ldots, l_K)$ be the stationary probability for state $(l_1, l_2, \ldots, l_i, \ldots, l_K)$. Then, the reverse blocking probability at station *i*, BL_i, is given as equation (1).

$$BL_i = \sum_{(l_1, \ldots, l_K) \in C_i} P(l_1, l_2, \ldots, l_j, \ldots, l_K) \tag{1}$$

where $C_i = \{(l_1, l_2, \ldots, l_K) \mid l_j = 0, 1, \ldots, B_j, B_j + 1, \text{ for } j \neq i, l_j = B_j + 2, \text{ for } j = i\}$.

Therefore, the total blocking probability at system, *BL*, is given as equation (2).

$$BL = \sum_{i=1}^{K} BL_i \, . \tag{2}$$

The throughput at station *i*, TH_i, is given as equation (3).

$$TH_i = \mu_i \left\{ 1 - \sum_{(l_1, \ldots, l_K) \in A_i} P(l_1, l_2, \ldots, l_j, \ldots, l_K) \right\} \tag{3}$$

where $A_i = \{(l_1, l_2, \ldots, l_K) \mid l_j = 0, 1, \ldots, B_j, B_j + 1, B_j + 2, \text{ for } j \neq i, l_j = 0, \text{ for } j = i\}$.

Therefore, the throughput at system, *TH*, is given as equation (4).

$$TH = \sum_{i=1}^{K} TH_i \ . \tag{4}$$

STATIONARY STATE EQUATIONS

In the case of K-station with buffer capacity B_i at station i, the stationary state equations for the sorting process are written as follows:

For $l_i = 0,1,...,B_i, B_i+1, B_i+2 \quad (i=1,...,K)$,

$$(\lambda\beta + \sum_{i=1}^{K} \mu_i \alpha_i) P(l_1,...,l_i,...,l_K) = \sum_{i=1}^{K} \sum_{x_i \in \{l_i - 1, l_i + 1\}} P(l_1,...,x_i,...,l_K) f_i(x_i), \tag{5}$$

$$P(l_1,...,l_i,...,l_j,...,l_K) = 0, \quad \textit{if there exist } l_i \textit{ and } l_j \textit{ such that } l_i = B_i + 2 \textit{ and } l_j = B_j + 2,$$

$$\sum_{\substack{l_i \in \{0,1,\cdots,B_i,B_i+1,B_i+2\} \\ (i=1,...,K)}} P(l_1,\cdots,l_i,\cdots,l_K) = 1, \tag{6}$$

where

$$\alpha_i = \begin{cases} 0 & \textit{if } l_i = 0 \\ 1 & \textit{if } l_i \geq 1 \end{cases}$$

$$\beta = \begin{cases} 0 & \textit{if there exists } l_i \textit{ such that } l_i = B_i + 2 \\ 1 & \textit{otherwise} \end{cases}$$

and $f_i(x_i) = \begin{cases} \mu_i & \textit{if } x_i = l_i + 1 \\ \lambda q_i & \textit{if } x_i = l_i - 1 \\ 0 & \textit{if } l_i = 0 \textit{ or } l_i = B_i + 2. \end{cases}$

s.t. $$\sum_{i=1}^{K} q_i = 1 \tag{7}$$

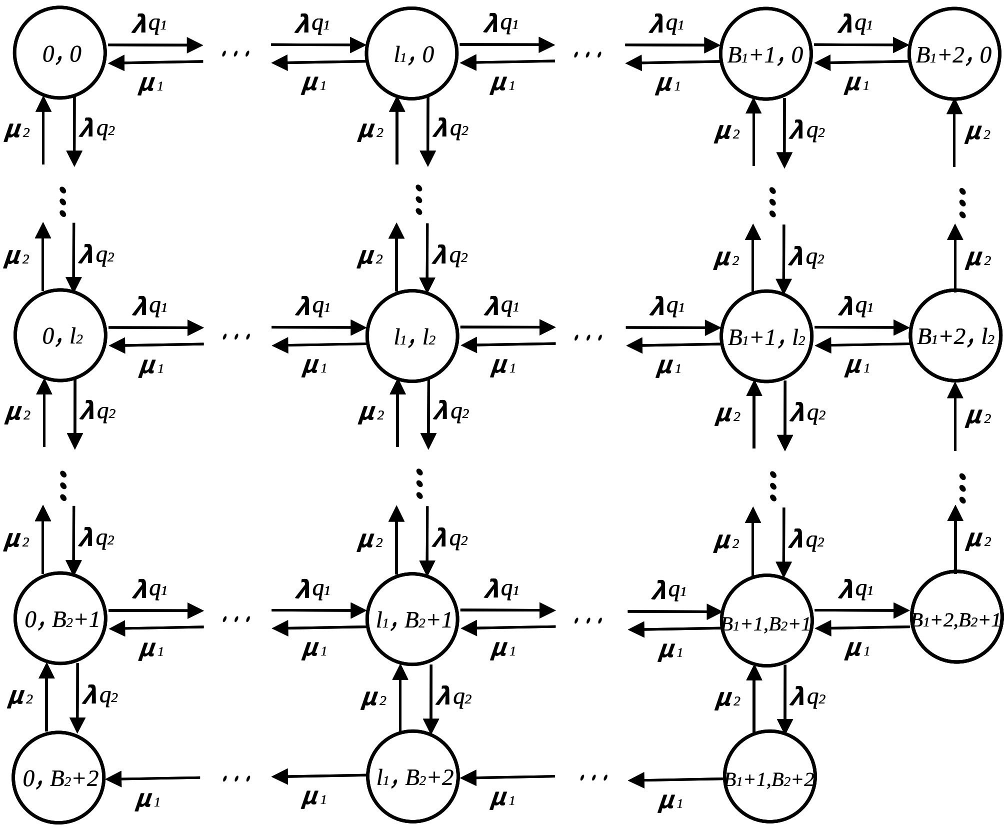

Fig. 2 A transition diagram of the states and transitions rates:
Case of 2-station with buffer capacity B_i at station i ($i=1,2$).

Fig. 2 shows a transition diagram of the states and transitions rates in the case of 2-station with buffer capacity B_i at station i ($i=1,2$). Its stationary state equations are written as follows:

$$\lambda P(0,0) = \mu_1 P(1,0) + \mu_2 P(0,1)$$
$$(\lambda + \mu_1)P(l_1,0) = \lambda q_1 P(l_1 - 1,0) + \mu_1 P(l_1 + 1,0) + \mu_2 P(l_1,1) \quad (l_1 = 1,\cdots,B_1 + 1)$$
$$\mu_1 P(B_1 + 2,0) = \lambda q_2 P(B_1 + 1,0) + \mu_2 P(B_1 + 2,1)$$
$$(\lambda + \mu_2)P(0,l_2) = \lambda q_2 P(0,l_2 - 1) + \mu_1 P(1,l_2) + \mu_2 P(0,l_2 + 1) \quad (l_2 = 1,\cdots,B_2 + 1)$$
$$\mu_2 P(0,B_2 + 2) = \lambda q_2 P(0,B_2 + 1) + \mu_1 P(1,B_2 + 2)$$
$$(\lambda + \mu_1 + \mu_2)P(l_1,l_2) = \lambda q_1 P(l_1 - 1,l_2) + \lambda q_2 P(l_1,l_2 - 1) + \mu_1 P(l_1 + 1,l_2) + \mu_2 P(l_1,l_2 + 1)$$
$$(l_1 = 1,\cdots,B_1 + 1, \quad l_2 = 1,\cdots,B_2 + 1)$$
$$(\mu_1 + \mu_2)P(B_1 + 2,l_2) = \lambda q_1 P(B_1 + 1,l_2) + \mu_2 P(B_1 + 2,l_2 + 1) \quad (l_2 = 1,\cdots,B_2 + 1)$$
$$(\mu_1 + \mu_2)P(B_1 + 2,B_2 + 1) = \lambda q_1 P(B_1 + 1,B_2 + 1)$$
$$(\mu_1 + \mu_2)P(l_1,B_2 + 2) = \lambda q_2 P(l_1,B_2 + 1) + \mu_1 P(l_1 + 1,B_1 + 2) \quad (l_1 = 1,\cdots,B_1 + 1)$$
$$(\mu_1 + \mu_2)P(B_1 + 1,B_2 + 2) = \lambda q_2 P(B_1 + 1,B_2 + 1)$$

NUMERICAL CONSIDERATIONS

(1) Behaviors of Throughput and Reverse Blocking

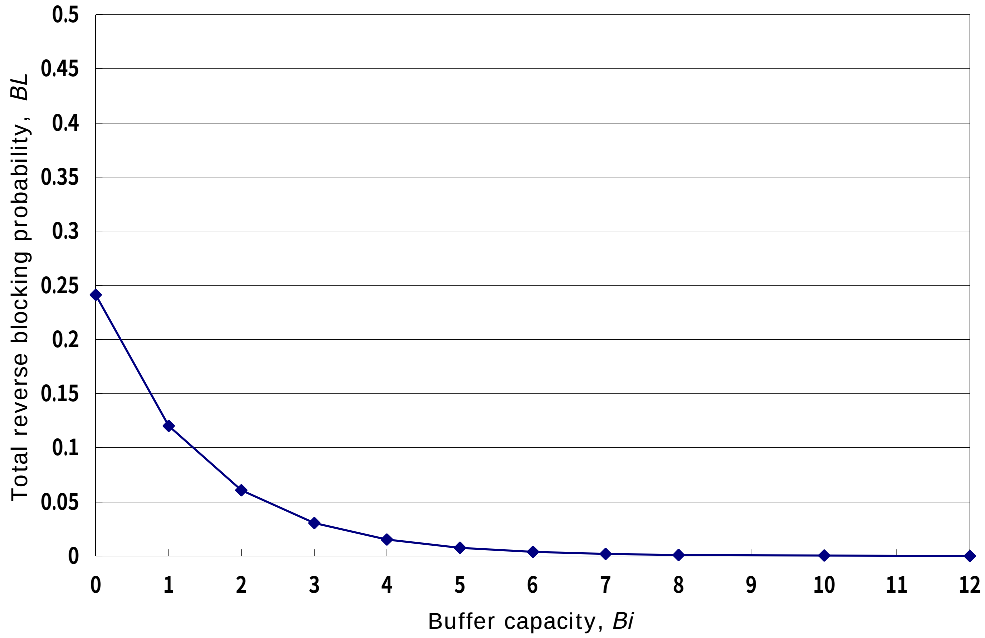

Fig. 3 Behavior of total reverse blocking probability *BL* for buffer capacity B_i:
Case of 2-station (K=2, $\lambda=1$, q_1=q_2=0.5, B_1=B_2, $\mu_1=\mu_2=1$)

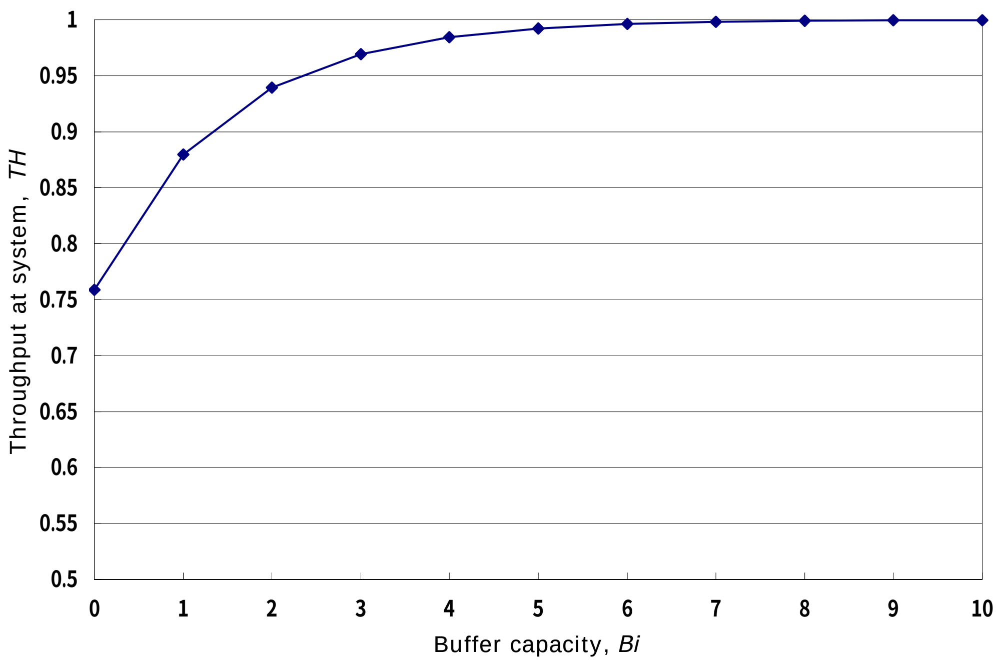

Fig. 4 Behavior of throughput at system, *TH*, for buffer capacity B_i:
Case of 2-station (K=2, $\lambda=1$, q_1=q_2=0.5, B_1=B_2, $\mu_1=\mu_2=1$)

Fig. 3 shows the behavior of the total reverse blocking probability *BL* for the buffer capacity B_i in the case of 2-station. As the buffer capacity B_i increases and approaches near B_i=6, the total reverse blocking probability *BL* also decreases rapidly. However, the blocking probability *BL* seldom decreases beyond B_i=6. Therefore, it is seen that there is an appropriate buffer capacity, which is sufficient to decrease the total reverse blocking.

Fig. 4 shows the behavior of the throughput at system, *TH*, for the buffer capacity B_i in the case of 2-station. Unlike the behavior of the total reverse blocking probability in Fig. 3, the throughput at system, *TH*, also increases as the buffer capacity B_i increases and approaches near B_i=6. It is seen that there is an inverse proportion between the reverse blocking probability and the throughput at the system. Therefore, the total reverse blocking probability should be decreased in order to increase the throughput at the system

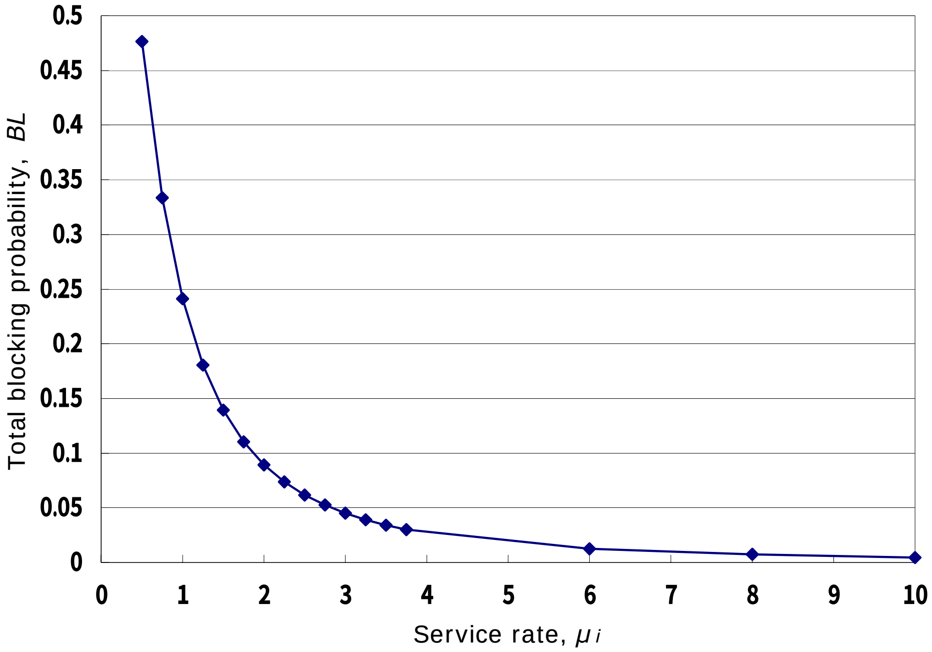

Fig. 5 Behavior of total reverse blocking probability *BL* for service rate μ_i : Case of 2-station (K=2, $\lambda = 1$, q_1=q_2=0.5, B_1=B_2=0, $\mu_1 = \mu_2$)

Fig. 5 shows the behavior of the total reverse blocking probability *BL* for service rate μ_i, in the case of 2-station. Similar to the behavior of the buffer capacity B_i in Fig. 3, the total reverse blocking probability *BL* also decreases as service rate μ_i increases.

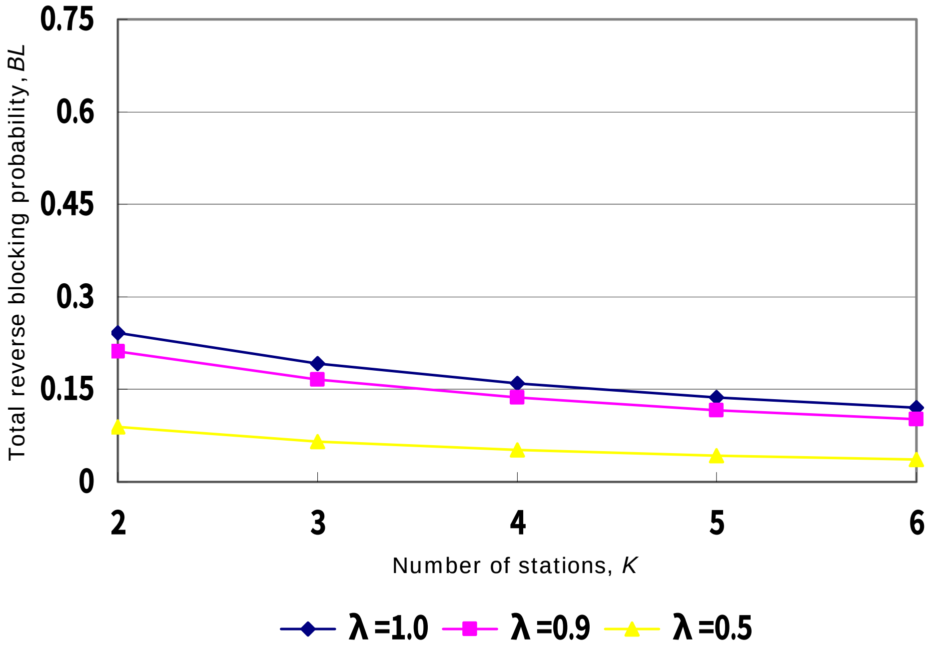

Fig. 6 Behavior of total reverse blocking probability *BL*
for the number of stations *K* in the succeeding stations of the sorting station
(q_i= 1 / *K*, B_i=0, $\mu_i = 1$ (i =1,2, ..., *K*))

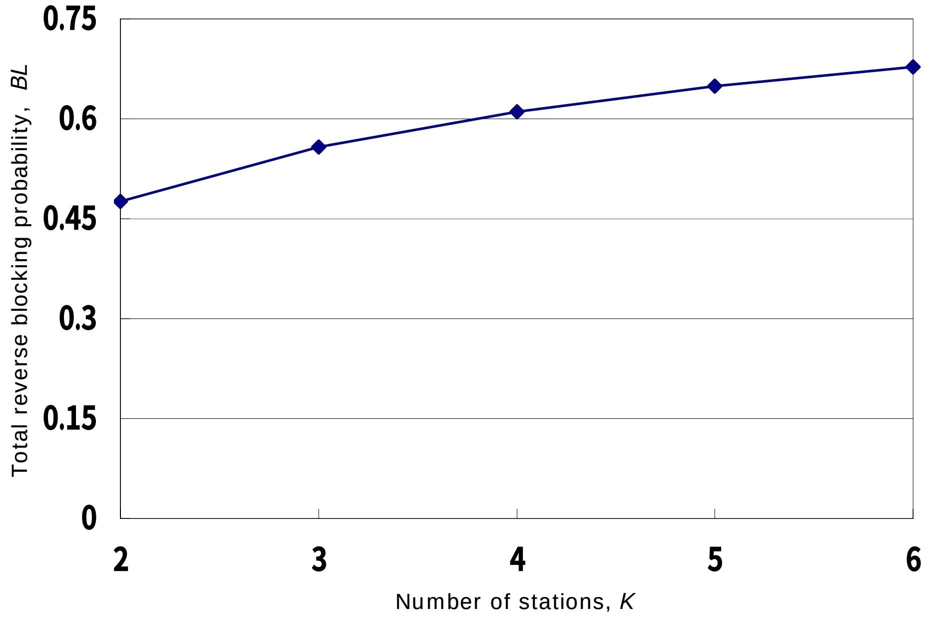

Fig. 7 Behavior of total reverse blocking probability *BL*
for the number of stations *K*: Case of a fixed total service capacity ($\sum \mu_i = 1$)
($\lambda = 1$, q_i= 1 / *K*, B_i=0, μ_i = 1 / *K* (i =1,2, ..., *K*))

Fig. 6 shows the behavior of the total reverse blocking probability *BL* for the number of stations *K* in the succeeding stations of the sorting station. As the number of stations *K* increases, the total reverse blocking probability *BL* also decreases. Because the total service capacity in the succeeding stations increases as the number of stations K increases, though the number of the blocking states in the transition diagram increases. On the other hand, the number of stations K indicates the number of product types which should be sorted at the sorting station. Therefore, the total reverse blocking probability decreases if the number of product types increases when the routing probability is the same for each station / product type as q_i= 1 / K.

In Fig. 6, the total service capacity in the succeeding stations increases as the number of stations / sorted product types K. A case of a fixed total service capacity in the succeeding stations is here considered. Fig. 7 shows the behavior of the total reverse blocking probability BL for the number of stations K in the case of a fixed total service capacity ($\sum \mu_i = 1$). Unlike Fig. 6, the total reverse blocking probability BL increases as the number of stations K increases in Fig. 7. It is seen that the smaller number of stations K, which also indicates the number of sorted product types, should be preferred in order to decrease the total reverse blocking probability BL when the total service capacity in the succeeding stations is limited.

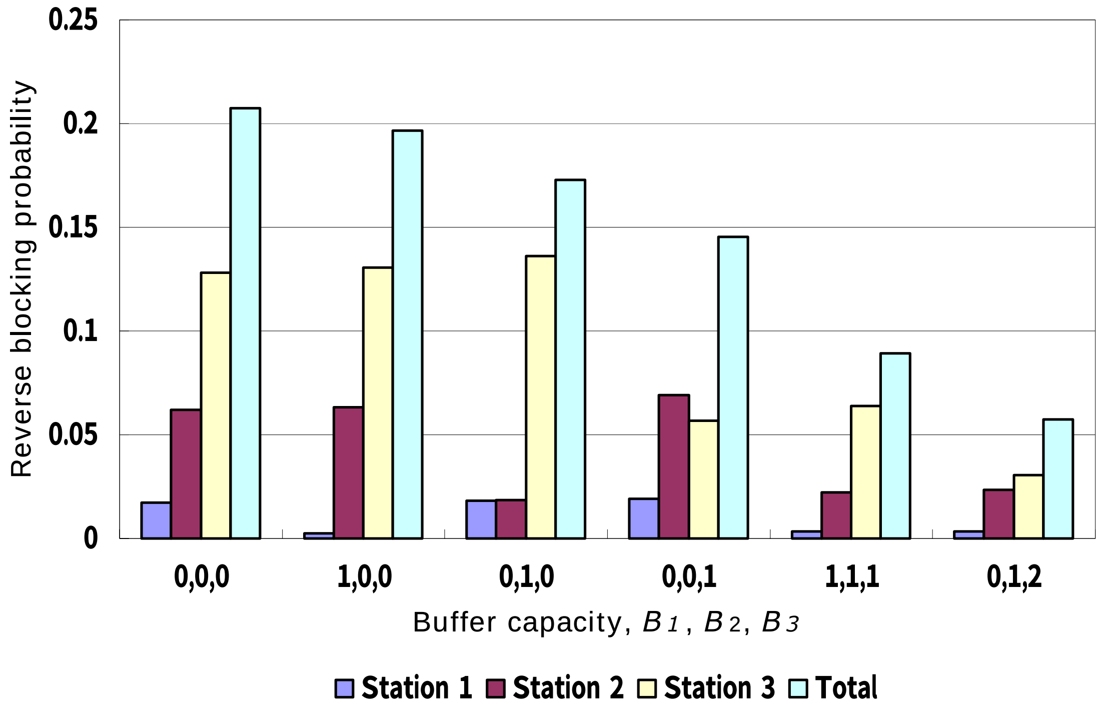

Fig. 8 Behavior of total reverse blocking probability BL for buffer capacity B_i: Case of different routing probability q_i
(K=3, $\lambda = 1$, q_1=0.17, q_2 =0.33, q_3=1, (q_1:q_2:q_3=1:2:3), B_i=0, $\mu_i = 1$ (i =1,2,3))

Fig. 8 shows the behavior of the total reverse blocking probability BL for the number of stations B_i in the case of different routing probability q_i (q_1=0.17, q_2 =0.33, q_3=1, (q_1:q_2:q_3=1:2:3)). Since the routing probability to station 3 is higher than that to other stations, the reverse blocking probability at station 3 decreases more than when at other stations, when the buffer capacity can be added at station 3. As the result, the total reverse blocking probability also decreases more. It is seen that there is an appropriate buffer balancing based on the routing probability q_i

On the other hand, the blocking probabilities at the other stations slightly increase when a buffer capacity is added to one station. Because the blocking probability at the station decreases by the additional buffer, and also input units to both the station and the other stations increase.

The similar behavior is seen in the case of 5-station shown in Fig. 9.

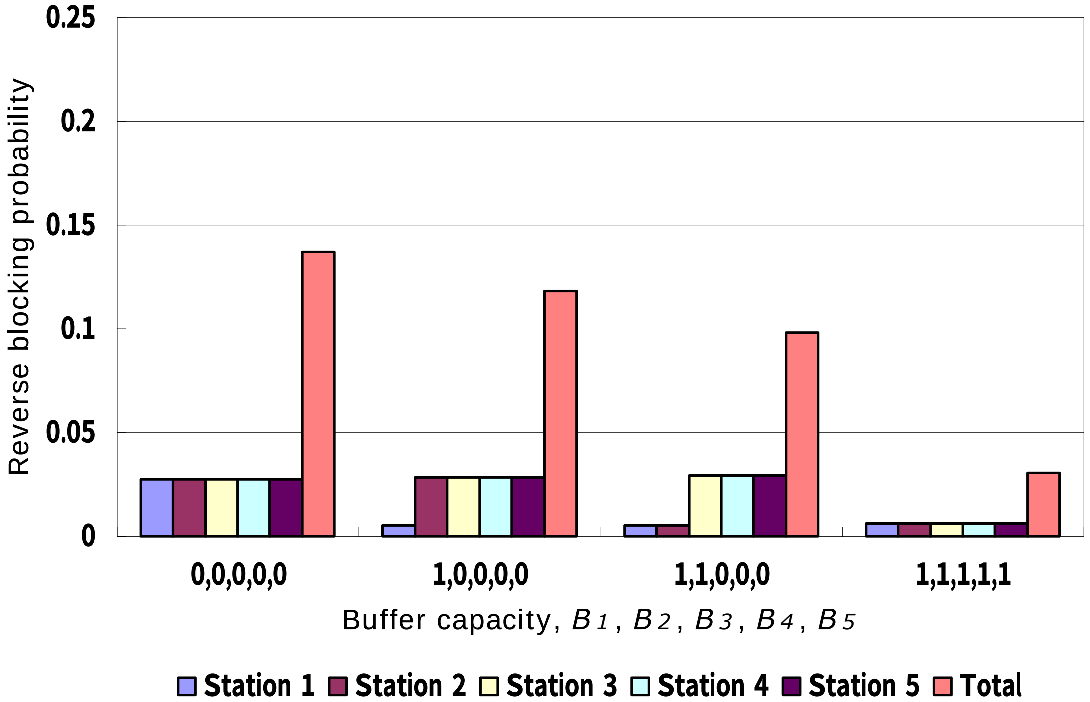

Fig. 9 Behavior of total reverse blocking probability *BL* for buffer capacity B_i: Case of 5-station
(K=5, $\lambda=1$, q_i=0.2, (q_1:q_2:q_3:q_4:q_5=1:1:1:1:1), B_i=0, $\mu_i=1$ (i =1,...,5))

(2) A Consideration of System Design

In order to decrease the reverse blocking and increase the throughput at system, it is obvious to increase the larger number of stations and buffer capacity by setting the additional them and the higher service rates with high speed machines and skilled operators. However, those additional service/buffer capacities also spend much cost, and they often have constrains such as total cost and physical spaces.

By setting the cost parameters for design parameters of the number of stations, buffer capacity and service rates, respectively, the total cost can be simply calculated and considered for the combinations among those design parameters in view of productivity and economics.

The total cost, TC, is set as equation (8).

$$TC = c_1 K + c_2 \sum_{i=1}^{K} B_i + c_3 \sum_{i=1}^{K} \mu_i \tag{8}$$

where c_1, c_2 and c_3 are respective cost coefficients of stations, buffer and service per unit time. The cost parameters are set as follows:

$c_1=8$, $c_2=2$, $c_3=5$

Table 1 An example of system design: Case of 2-station

K	λ	q_1	q_2	B_1	B_2	μ_1	μ_2	$1-\Sigma P_1(0)$	$1-\Sigma P_2(0)$	BL_1	BL_2	BL	TH_1	TH_2	TH	TC
2	1	0.5	0.5	0	0	1	0.5	0.307	0.613	0.093	0.293	0.387	0.307	0.307	0.613	28
2	1	0.5	0.5	0	0	1	1	0.379	0.379	0.121	0.121	0.241	0.379	0.379	0.759	30
2	1	0.5	0.5	0	0	1	2	0.413	0.206	0.135	0.040	0.175	0.413	0.413	0.825	35
2	1	0.5	0.5	0	0	1	3	0.421	0.140	0.139	0.019	0.158	0.421	0.421	0.842	40
2	1	0.5	0.5	0	1	1	1	0.407	0.407	0.133	0.052	0.185	0.407	0.407	0.815	32
2	1	0.5	0.5	0	2	1	1	0.419	0.419	0.139	0.023	0.162	0.419	0.419	0.838	34
2	1	0.5	0.5	0	3	1	1	0.424	0.424	0.141	0.010	0.151	0.424	0.424	0.849	36
2	1	0.5	0.5	1	1	1	1	0.440	0.440	0.060	0.060	0.120	0.440	0.440	0.880	34
2	1	###	0.67	0	0	1	1	0.249	0.498	0.057	0.195	0.253	0.249	0.498	0.747	30
2	1	###	0.75	0	0	1	1	0.183	0.550	0.033	0.233	0.266	0.183	0.550	0.734	30
2	1	0.2	0.8	0	0	1	1	0.145	0.579	0.021	0.255	0.277	0.145	0.579	0.723	30
2	2	0.5	0.5	0	0	1	1	0.524	0.524	0.238	0.238	0.476	0.524	0.524	1.048	30
2	3	0.5	0.5	0	0	1	1	0.581	0.581	0.306	0.306	0.613	0.581	0.581	1.162	30

Table 2 An example of system design: Case of the number of stations changed
(K=2,3,5, $\lambda=1$, $q_i=1/K$, $B_i=0$, $\mu_i=1$)

K	BL	TH	TC
2	0.241	0.759	30
3	0.192	0.808	45
5	0.137	0.863	65

Table 1 shows an example of the system design in the case of 2-station. The throughput at station 1 equals one at station 2 when $q_1=q_2=0.5$, even though stations 1 and 2 have the different design parameters, such as the service rates and buffer capacity. It is considered that the throughput balance at stations 1 and 2 only depends on the routing probability to station 1 and 2, respectively.

Table 2 shows an example of the system design in the case of number of stations changed. As the number of stations K increases, the reverse blocking at system, BL, decreases. Therefore, the throughput at system, TH, and the total cost TC increase.

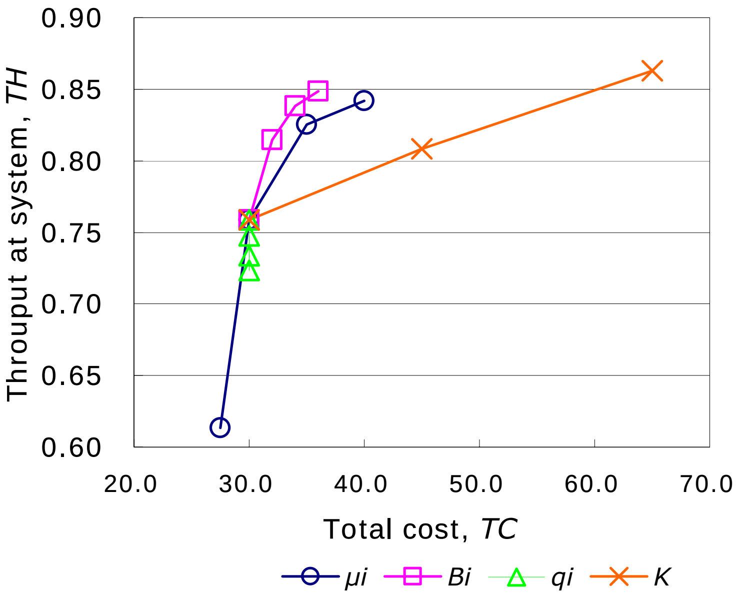

Fig. 10 Relations between total cost *TC* and throughput at system, *TH* for the changes of the service rate μ_2, the buffer capacity B_2, the routing probability to station 1, q_1, and the number of station *K* ($\lambda=1$, μ_2=0.5,1,2,3, B_2=0,1,2,3, q_1=0.2,0.25,0.33,0.5, K =3,4,5)

Based on Tables 1 and 2, Fig. 10 shows the relations between the total cost *TC* and the throughput at system, *TH*. From the base line (*TC*, *TH*)=(30, 0.759) in the case of 2-station with μ_2=1, B_2=0, q_1=q_2=0.5 and K=2, the throughput at system, *TH*, increases as the service rate μ_2, the buffer capacity B_2, the routing and the number of station *K* increase, i.e., the total cost *TC* increases. In this example, the increase of the buffer capacity B_2 is the most effective in design parameters to improve the throughput *TH* with lower total costs.

SUMMARY AND FUTURE STUDIES

This study presents a queuing model of the sorting process with reverse blocking, analyzes the throughput of the process and discusses the system performance. First, the sorting process with the reverse blocking is generally modeled as a queuing system. Next, the stationary state equations of the system are formulated, and the objective function is set as the throughput. Finally, the system performance is discussed by using mathematical and numerical analysis in cases of a different number of stations and buffers, and also an example of the system design is shown and discussed in view of the throughput and total cost. The main conclusions drawn are as follows:

- The total reverse blocking probability should be decreased in order to increase the throughput at the system.
- There is an appropriate buffer / service rates balancing among each station based on the routing probability.

- The total reverse blocking probability decreases if the number of product types / stations increases when the routing probability is the same for each station. However, the smaller number of product types / stations should be preferred when the total service capacity in the succeeding stations is limited.
- The throughput balance at each station only depends on the routing probability. But the increase of service rate and buffer capacity contributes to the increase of the throughput at the whole system as well as the throughput at each relevant station.
- A consideration of the total cost based on the design parameters is helpful for system designers and managers.

Further studies should develop an approximation (Asadathorn and Chao, 1999), build this sorting process with reverse blocking into the entire disassembly and/or inverse manufacturing systems, etc.

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DYNAMIC FLUCTUATION OF INVENTORY LEVELS IN A CLOSED-LOOP SUPPLY CHAIN

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ABSTRACT

Most of firms have challenged to decrease their environmental impacts and some firms have constructed recycling-oriented manufacturing system. The feature of the system is to collect post-consumer products and utilize the available resources of the products for producing new products. Thereby, the flow of products constitutes a closed-loop, and it is vital to effectively manage inventory levels and processing rates at sectors in the system in order to achieve economically effective products flow. The paper develops a model of closed-loop supply chain and clarifies dynamic behaviour of inventory levels. The model consists of four sectors, which are raw-material supplier, products manufacturer, consumer, and recycler. The products flow is formulated as several differential equations and the dynamic behaviour is analyzed using Laplace transform. Usually, the inventory level of post-consumer products fluctuates widely in comparison with the inventory level of new products, and then several methods to decrease the fluctuation are discussed.

INTRODUCTION

One of the issues with which our society is faced is an environmental problem. Various approaches are tried to tackle with the problem. Most of firms have also challenged to decrease their environmental impacts and some firms have constructed recycling-oriented manufacturing systems. The feature of the system is to collect post-consumer products and utilize the available resources of the products for producing new products [Hoshino et al. (1995)]. Thereby, the flow of products constitutes a closed-loop, and it is vital to effectively manage inventory levels and processing rates at sectors in the system in order to achieve economically effective products flow. The problem is sometimes called “a closed loop supply chain”, which is considered one of subjects of the supply chain management [Shapiro (2001)].

In the paper, a model of the closed-loop supply chain is developed and dynamic behaviour of inventory levels in the chain is clarified. The model consists of four sectors, which are a raw-material supplier, a product’s manufacturer, consumers, and a recycler. The products flow is formulated as several differential equations and the dynamic behaviour is obtained [Yura (2000)]. In the paper, the method to get the dynamic behaviour is explained and then the property is shown. Usually, the inventory level of post-consumer products fluctuates widely in comparison with the inventory level of new products. Therefore, several methods to decrease the fluctuation are discussed.

MODEL OF CLOSED LOOP SUPPLY CHAINS

A model of closed loop supply chains is shown in Figure 1. The model consists of four sectors, which are a raw-material supplier (S), a products manufacturer (M), consumers (C), and a recycler (R).

A raw-material supplier transforms virgin and recyclable resources into the raw-material of products. The raw-material is machined and the produced parts are assembled into a product in a manufacturer. The product is sold to consumers. The demand of products from consumers varies with time. After consumption the used-products are collected from the consumers. The recycler extracts recyclable resource from the collected products. Then, the recyclable resource is sent to the raw-material supplier and transformed to the raw-material of new products.

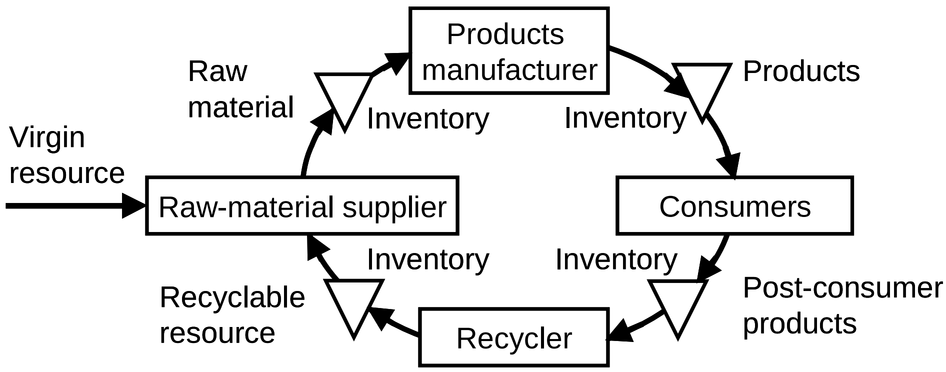

Figure 1: A model of closed loop supply chains

There are several recycling laws on products in Japan. They describe that a recycling rate of resource should be greater than a predetermined value. Then, the workflow from the consumers to the manufacturer in the closed loop chain should be maintained so as to achieve the predetermined recycling rate.

FORMULATION

(1) Symbols

The workflow in the model is formulated, using the symbols shown in Table 1 (on the next page).

(2) Workflow and inventory levels

The amount of collected products at time t is obtained by integrating the sales multiplied by probability density $f(u)$.

$$C_O(t) = \int_0^t f(u)\ C_I(t-u)\, du \tag{1}$$

From the relation of inputs and outputs, the level of inventory between the consumers and the recycler satisfies the following equation.

$$\frac{d\, I_{CR}(t)}{dt} = C_O(t - T_{CR}) - R_I(t) \tag{2}$$

Table 1: List of symbols used in this article

B_a	Transformation efficiency at sector a ($a = S$, M, or R).
B	The product of transformation efficiencies (=$B_M B_R B_S$).
C_M	Mean of product's demand for a period (pcs/day).
$C_{\mathrm{I}}(t)$	Demand on the product at time t (pcs).
$C_{\mathrm{O}}(t)$	Used-products collected from consumers at time t (pcs).
$f(u)$	Probability density that a product is collected at usage period u.
$I_{ab}(t)$	Inventory level between sectors a and b, where a and b are S (raw-material supplier), M (manufacturer), C (consumers), or R(recycler) (pcs).
$M_{\mathrm{I}}(t)$	Raw-material used in producing products in a manufacturer at time t (pcs).
$M_{\mathrm{O}}(t)$	Products produced in a manufacturer at time t (pcs).
P_a	Lead time of processing in sector a ($a = S$, M, or R) (day).
$R_{\mathrm{I}}(t)$	Used-products processed in a recycler at time t (pcs).
$R_{\mathrm{O}}(t)$	Recyclable resource outputted from a recycler at time t (pcs).
$S_{\mathrm{I}}(t)$	Recyclable resource processed in a raw-material supplier at time t (pcs).
$S_{\mathrm{O}}(t)$	Raw-material produced using recyclable resource in a raw-material supplier at time t (pcs).
T	Mean lifetime of a product (day)
T_{ab}	Transportation time between sectors a and b (day).
$V_{\mathrm{I}}(t)$	Virgin resource processed in a raw-material supplier at time t (pcs).
$V_{\mathrm{O}}(t)$	Raw-material produced using virgin resource in a raw-material supplier at time t (pcs).

The recyclable resource is outputted from the recycler with delay P_R. Then, $R_{\mathrm{O}}(t)$ is,

$$R_{\mathrm{O}}(t) = B_R \, R_{\mathrm{I}}(t - P_R) \tag{3}$$

Inventory level $I_{RS}(t)$ satisfies the following equation by the similar reason.

$$\frac{d\, I_{RS}(t)}{dt} = R_{\mathrm{O}}(t - T_{RS}) - S_{\mathrm{I}}(t) \tag{4}$$

The raw-material supplier transforms the recyclable resource and virgin resource to the raw-material. The relation is expressed by the following equations.

$$S_{\mathrm{O}}(t) = B_S \, S_{\mathrm{I}}(t - P_S) \tag{5}$$

$$V_{\mathrm{O}}(t) = B_S \, V_{\mathrm{I}}(t - P_S) \tag{6}$$

Inventory level $I_{SM}(t)$ between the raw-material supplier and the manufacturer is given by,

$$\frac{d\, I_{SM}(t)}{dt} = S_{\mathrm{O}}(t - T_{SM}) + V_{\mathrm{O}}(t - T_{SM}) - M_{\mathrm{I}}(t) \tag{7}$$

The production volume of the manufacturer at time t, $M_O(t)$, is,

$$M_O(t) = B_M\ M_I(t - P_M) \tag{8}$$

Inventory level $I_{MC}(t)$ between the manufacturer and the consumers is given by,

$$\frac{d\,I_{MC}(t)}{dt} = M_O(t - T_{MC}) - C_I(t) \tag{9}$$

The above equations (1) to (9) formulate the workflow and inventory levels in the model.

(3) Recycling rate
In the article, the recycling rate is defined as the ratio of recycled raw-material to the total usage of raw-material at the entrance of the manufacturer. The recycling rate, r, is shown by,

$$r = \frac{S_O(t - T_{SM})}{M_I(t)} \tag{10}$$

ANALYSIS

(1) Differential equation of inventory levels
In order to analyze dynamic behavior of the model, the differential equations of the inventory levels are obtained from equations (1) to (9).
From equations (1) and (2), the equation of inventory level between the consumers and the recycler, $I_{CR}(t)$, is shown by the following equation.

$$\frac{d\,I_{CR}(t)}{dt} = \int_{0}^{t - T_{CR}} f(u)\ C_I(t - T_{CR} - u)\, du\ - R_I(t) \tag{11}$$

Similarly, the equations for $I_{RS}(t)$, $I_{SM}(t)$, and $I_{MC}(t)$ are obtained as follows.

$$\frac{d\,I_{RS}(t)}{dt} = B_R\ R_I(t - T_{RS} - P_R) - S_I(t) \tag{12}$$

$$\frac{d\,I_{SM}(t)}{dt} = B_S\ S_I(t - T_{SM} - P_S) + B_S\ V_I(t - T_{SM} - P_S) - M_I(t) \tag{13}$$

$$\frac{d\,I_{MC}(t)}{dt} = B_M\ M_I(t - T_{MC} - P_M) - C_I(t) \tag{14}$$

Solving the above differential equations, we get the dynamic fluctuations of the inventory levels.

(2) Products collected from the consumers
The amount of used-products collected from the consumers depends on the sales and their durations of usage by the consumers. It is assumed that probability density function, $f(u)$, is given by the following equation.

$$f(u) = \begin{cases} (r/BT^2)\,u & (0 \le u \le T) \\ 2\,r/BT - (r/BT^2)\,u & (T < u \le 2T) \\ 0 & (2T < u) \end{cases} \quad (15)$$

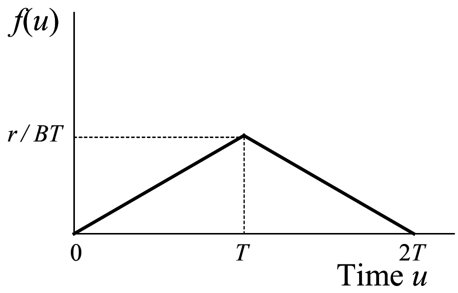

Figure 2: Probability density function $f(u)$

where, T is the mean lifetime of the product and B denotes $B_M B_R B_S$. The ratio of collectable used-products to sold products is r/B. The Laplace transform of $f(u)$, $\Phi(s)$, is obtained as follows.

$$\Phi(s) = (B / T^2 s^2)(1 - 2\,e^{-Ts} + e^{-2Ts}) \quad (16)$$

(3) Processing rules of each sector in the model

The workflow in the model depends on the processing rule in each sector. In this paper, the case in which the processing volume is fixed at the mean of product's demand. Let C_M denote the mean value of the demand for a period. Further, the recycling rate is shown by r, because the rate does not depend on time. Then, the amount of processing in each sector is given by the following equation, respectively.

$$M_I(t) = C_M / B_M \quad (17)$$

$$R_I(t) = r\,C_M / (B_M B_R B_S) \quad (18)$$

$$S_I(t) = r\,C_M / (B_M B_S) \quad (19)$$

$$V_I(t) = (1 - r)\,C_M / (B_M B_S) \quad (20)$$

In the case, substituting the above relation into equations (12) and (13), we have the following relations.

$$\frac{d\,I_{RS}(t)}{dt} = 0 \quad (21)$$

$$\frac{d\,I_{SM}(t)}{dt} = 0 \quad (22)$$

(4) Fluctuation of demand

The product's demand for a unit period varies with time. In this article, the demand rate is given by the following equation.

$$C_I(t) = C_M + C \sin \omega t \quad (23)$$

The above equation shows that the mean value of the demand rate is C_M and the rate deviates according to the periodic fluctuation. The Laplace transform of $C_I(t)$ is given by,

$$\Theta(s) = \frac{C_M}{s} + \frac{C\omega}{s^2 + \omega^2} \quad (24)$$

(5) Dynamic behavior of inventory levels

In the case that the processing rate is fixed, the inventory levels $I_{CR}(t)$ and $I_{MC}(t)$ change dynamically. The dynamical behaviors are obtained from equations (11) and (12).

The Laplace transform of equation (11) using equation (18) is,

$$s\Psi(s) = \Theta(s)\ \Phi(s)\ e^{-T_{CR}s} - \frac{rC_M}{B_M B_R B_S\ s} + I_{CR}(0) \tag{25}$$

where $\Psi(s)$ denotes Laplace transform of $I_{CR}(t)$.

Substituting equations (16) and (24) into equation (25), and then making inverse transformation for the obtained equation, we have the behavior of inventory level $I_{CR}(t)$ for $t > 2T+T_{CR}$ as follows. Usually, negative inventory level is not allowed, and so $I_{CR}(0)$ should be sufficiently large so that $I_{CR}(t)$ can be greater than or equal to zero.

$$\begin{aligned} I_{CR}(t) &= rC\{\cos\omega(t - T_{CR}) - 2\cos\omega(t - T - T_{CR}) + \cos\omega(t - 2T - T_{CR})\} / (BT^2\omega^3) \\ &\quad + rC / (B\omega) - rC_M\{T + T_{CR}) / B + I_{CR}(0) \end{aligned} \tag{26}$$

Similarly, using equations (17), (24) and (14), the behavior of inventory level $I_{MC}(t)$ is obtained as follows.

$$I_{MC}(t) = C\,(\cos\omega t - 1) / \omega + I_{MC}(0) \tag{27}$$

From equations (26) and (27), it is clear that the following property holds.

(A) The third term of the right hand side of equation (26) tends to be larger than the other terms. It requests that $I_{CR}(0)$ should be sufficiently large. The reason is that the recycling rate is predetermined and the rate must be satisfied.

(B) In order to decrease inventory level $I_{CR}(t)$, it is useful to increase transformation efficiency B and mean products lifetime T. They might contribute to enhance the environmental performance of the chain.

(C) When the frequency of product demand fluctuation becomes low, both of inventory levels $I_{CR}(t)$ and $I_{MC}(t)$ increases. In the case, it might be possible to adapt processing rate of each sector to the demand fluctuation.

(D) Usually value ω is smaller than 1 and inventory level $I_{CR}(t)$ is larger than $I_{MC}(t)$. If ω is very large, $I_{CR}(t)$ becomes less than or equal to $I_{MC}(t)$.

CONCLUSIONS

This paper develops a model for a closed-loop supply chain. Especially, it is concerned with the case where all the sectors of the chain keep a constant processing rate of the works. The workflows in the model are expressed by differential equations and a dynamic behavior of inventory levels are obtained under periodic fluctuations of demand. Some property of the behavior is clarified and some methods to decrease the inventory levels are discussed.

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Influence of Information about Proportion of Nonconforming Items on Inventory Policy

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ABSTRACT
Replenishment orders may contain some nonconforming items as a result of imperfect production and inspection by suppliers, and/or damage in transit. This paper deals with a periodic order-up-to S inventory model provided that some nonconforming items may be included in the replenishment. Further, we assume the proportion of nonconforming items to be a random variable. The operating characteristics of such a model are analyzed. Then, we consider an economical inventory policy under some uncertain information. Lastly, we investigate the model through numerical examples.

INTRODUCTION
An implicit assumption in most of the inventory models in the literature is that the replenishment will not include any nonconforming items. It is often not true. The replenishment of suppliers may include some nonconforming items as a result of imperfect production and inspection by the suppliers, and /or damage in transit (Moinzadeh and Lee, 1987).

The nonconforming item is equivalent to a phony stock. The inclusion of nonconforming items may cause not only the extra holding cost in the inventory management but also the compensation due to the delivery of nonconforming items to customers. Therefore, the nonconforming items need to be removed from the stock by inspection beforehand. For the purpose of removing the nonconforming items completely, it is desirable to execute the total inspection for the replenishment items. In contrast, it is impossible to deny that the removal of nonconforming items may lead to the further shortage of items. Then, the shortage may bring many backlogs until the next replenishment. Therefore, we should consider the impact of nonconforming items in the planning of the inventory policy.

Moinzadeh and Lee (1987) have considered a continuous review (Q,R) inventory model provided that the replenishment of suppliers includes some nonconforming items, where Q and R imply order quantity and reorder point, respectively. Then, they have formulated two approaches using the limiting distribution of the inventory position and the approximation of Hardy and Whitin (1963), where they have assumed that demand follows a Poisson process. Paknejad, Nasri and Affisco (1995) have researched a continuous review (Q,R) inventory model provided that demand has a known probability density function. Further, Wu and Ouyang (2001) have proposed a continuous review inventory model with nonconforming items in which the lead time is a decision variable in addition to the order quantity and the reorder point.

A lot of inventory models have been considered until now. An order-up-to S inventory model is well known as one of the major inventory models for periodic review systems. In the model, a sufficient order is issued to bring the current inventory position up to a level S at each review epoch, where S is a model parameter to express an inventory policy. Note that in this model, the quantity of each order at the review epoch can vary due to the uncertainty of demands (Hardy and Whitin, 1963).

The number of nonconforming items is frequently described by a binomial distribution (Wu and Ouyang, 2001). Therefore, the stochastic property about the number of nonconforming items is derived from the order quantity and the proportion of nonconforming items. The order-up-to S inventory model is different from the continuous review (Q,R) inventory model in the point that each order quantity can be distinct. Therefore, the fluctuation of the quantity ordered may lead to the expansion in the variance of the number of nonconforming items. Also, Wu and Ouyang (2001) have assumed the proportion of nonconforming items to be probabilistic. Similarly to the order quantity, the fluctuation of the proportion of nonconforming items should lead to the expansion in the variance of the number of nonconforming items. Naturally, those fluctuations may have an influence on the economical inventory policy. Therefore, the sufficient planning for the inventory policy should be needed.

In this paper, we deal with the inventory model under the assumption that the replenishment items ordered include some nonconforming items. We formulate the order-up-to S inventory model in the case that the proportion of nonconforming items is probabilistic, and then consider an economical inventory policy. On determining the economical policy, we assume that the distribution about the demand and the proportion of nonconforming items is unknown but those first two moments are respectively given. Using the method of Moon and Gallego (1994), we obtain a quasi-economical policy based on the min-max principle.

FORMULATION OF THE MODEL

We define the following notation in this paper:

S base inventory level, where is a decision variable.

L replenishment lead time, where is a constant.

d_t demand in period t, where $E[d_t]=\mu$ and $Var[d_t]=\sigma^2$.

z_t order quantity in period t.

p_t proportion of nonconforming items for z_t, where $E[p_t]=p$ and $Var[p_t]=\delta^2$.

r_t number of nonconforming items included in z_t, where follows a binomial distribution $B(p_t, z_t)$.

c_H inventory holding cost.

c_B backordering cost.

$[x]^+$ $\max\{0,x\}$.

$[x]^-$ $\max\{0,-x\}$.

Then, the following conditions are assumed:

1. The demand d_t and the proportion p_t are independent and identically distributed, provided that its distribution function is unknown but its first two moments are finite and known, respectively.
2. A replenishment order from the supplier may contain some nonconforming items. After the arrival of the replenishment, all the items are inspected and all the nonconforming items are discovered and removed.
3. The stochastic processes d_t and p_t are independent of each other.
4. Demand exceeding the stock is backlogged, where a fixed penalty is incurred per unit period.

We consider a supplier and a retailer who sells a single item to customers. The retailer reviews the inventory periodically. The interval between successive reviews is considered to be unit period, i.e., 1. At each review epoch, a replenishment order to the supplier is issued to raise the inventory position to S, where the inventory position is given as the amount of the on-hand inventory plus the on-order replenishment minus the backordered demands. In other words, the retailer practices the order-up-to S inventory policy.

The timing of the events is as follows (Lee, Padmanabhan and Whang, 1997): At the beginning of period t, a decision to order a quantity z_t is made. Next, the replenishment items ordered L period ago arrive. Then, the retailer executes the inspection and removes the nonconforming items. Lastly, demand is fulfilled, where excess demand is backlogged. The holding and backordering costs for the inventory at the end of the period t are charged.

ANALYSIS OF THE MODEL

We consider the stochastic property about the number of nonconforming items. The conditional expectation and variance of r_t for given z_t and p_t are obtained as follows:

$$E\left[r_t \middle| z_t, p_t\right] = p_t z_t, \tag{1}$$

$$Var\left[r_t \middle| z_t, p_t\right] = p_t\left(1 - p_t\right) z_t. \tag{2}$$

Then, we derive the following equations about the conditional expectation and variance of r_t for given p_t.

$$E\left[r_t \middle| p_t\right] = p_t E\left[z_t \middle| p_t\right], \tag{3}$$

$$Var\left[r_t \middle| p_t\right] = p_t\left(1 - p_t\right) E\left[z_t \middle| p_t\right] + p_t^2 Var\left[z_t \middle| p_t\right]. \tag{4}$$

In the detail, see appendix A. Further, the expectation and variance of r_t are given as follows:

$$E\left[r_t\right] = E\left[p_t\right] E\left[z_t\right], \tag{5}$$

$$Var\left[r_t\right] = E\left[z_t\right]\left(E\left[p_t\right] - E\left[p_t^2\right]\right) + E\left[z_t^2\right] E\left[p_t^2\right] - \left(E\left[p_t\right] E\left[z_t\right]\right)^2 \tag{6}$$

In the detail, see appendix B.

The order quantity z_t is given as

$$z_t = \begin{cases} S - S_0, & t = 1, \\ d_{t-1}, & t = 2, \cdots, L+1, \\ d_{t-1} + r_{t-L-1}, & t = L+2, \cdots \end{cases} \tag{7}$$

where $S_0(\le S)$ means the initial inventory position and is a constant. The expectation and variance of z_t is derived from (7) using (5) and (6). Let t denote $t = n(L+1)+m$ using n and m, where $n = 0, 1, \cdots,$ and $m = 1, 2, \cdots, L+1$. We obtain the following expectation and variance of z_t:

$$E[z_t] = \mu \frac{1-p^n}{1-p} + p^n E[z_m], \tag{8}$$

$$\begin{aligned} Var[z_t] = &\left\{ \sigma^2 + \frac{\mu}{1-p}\left\{ p - \left(p^2+\delta^2\right)\right\} + \delta^2 \left(\frac{\mu}{1-p}\right)^2 \right\} \left\{ \frac{1-\left(p^2+\delta^2\right)^n}{1-\left(p^2+\delta^2\right)} \right\} \\ &+ \left\{ p^n - \left(p^2+\delta^2\right)^n \right\} \left\{ E[z_m] - \frac{\mu}{1-p} \right\} \left\{ 1 + \frac{2\delta^2}{p-\left(p^2+\delta^2\right)} \left(\frac{\mu}{1-p}\right) \right\} \\ &- \left\{ p^{2n} - \left(p^2+\delta^2\right)^n \right\} \left\{ \frac{\mu}{1-p} - E[z_m] \right\}^2 + \left(p^2+\delta^2\right)^n Var[z_m], \end{aligned} \tag{9}$$

where

$$E[z_m] = \begin{cases} S - S_0, & m = 1 \\ \mu, & m = 2, \cdots, L+1 \end{cases},$$

$$Var[z_m] = \begin{cases} 0, & m = 1 \\ \sigma^2, & m = 2, \cdots, L+1 \end{cases}.$$

In the detail, see appendix C.

We define a cost function for the purpose of obtaining an economical inventory policy. In this paper, we consider the cost factors to be holding cost and shortage penalty about items. Therefore, the cost function in period t is given as follows:

$$\begin{aligned} C_t(S) &= c_H E\left[S - \sum_{i=t-L}^{t} r_{i-L} - \sum_{i=t-L}^{t} d_i \right]^+ + c_B E\left[S - \sum_{i=t-L}^{t} r_{i-L} - \sum_{i=t-L}^{t} d_i \right]^- \\ &= c_H E\left[S - \sum_{i=t-L}^{t-L} z_{i+1} \right]^+ + c_B E\left[S - \sum_{i=t-L}^{t} z_{i+1} \right]^- . \end{aligned} \tag{10}$$

For calculating (10), the distribution function of z_t is required, where z_t is given by the distribution about the demand and the nonconforming items. Moinzadeh and Lee (1987) and Paknejad, Nasri and Affisco (1995) have assumed those distribution to be known.

On the other hand, Moon and Gallego (1994) have proposed an approach to an economical inventory policy using first two moments of demand distribution. The approach is called 'distribution free procedure'. The distribution free procedure consists of finding the most unfavourable distribution in the class of the distribution function with same first two moments for each decision variable and minimizing the defined cost function over the decision variable. Then, this optimization procedure can be interpreted as one based on the min-max principle.

From applying the distribution free procedure to (10), we obtain the following cost function:

$$C_t^{\mathrm{DFP}}(S)=\frac{c_H+c_B}{2}\left\{\left(S-\sum_{i=t-L}^{t-L}E[z_{i+1}]\right)^2+\sum_{i=t-L}^{t-L}Var[z_{i+1}]\right\}^{\frac{1}{2}}+\frac{c_H-c_B}{2}\left(S-\sum_{i=t-L}^{t-L}E[z_{i+1}]\right), \qquad (11)$$

where $C_t^{\mathrm{DFP}}(S)\geq C_t(S)$ for all S. In the detail, see appendix D. Then, the operating cost for period t can be evaluated using (11). Through (11) based on the min-max principle, we obtain a kind of quasi-economical inventory policy.

The distribution of z_t for every period t is distinct. The change of the stochastic property of z_t can be interrupted from (8) and (9). For the purpose of obtaining the economical inventory policy, an expected total discounted cost is sometimes used (Lee, Padmanabhan and Whang, 1997). In this approach, the explicit solution may not be always given. Because the change of the stochastic property of z_t depends on the initial value S_0, the economical inventory policy may be sensitive to S_0.

On one hand, it is shown from (8) and (9) that the stochastic property of z_t converges as time passes. Moinzadeh and Lee (1987) and Cheung and Zhang (1999) have proposed an economical policy using the limiting distribution of the inventory position. Therefore, we consider the limiting distribution of the inventory position. The limiting distribution of the inventory position is concerned with the limiting distribution of z_t in this paper. The following limits of the value in the stochastic property of z_t are obtained form (8) and (9):

$$E[z_\infty]\equiv\lim_{t\to\infty}E[z_t]=\frac{\mu}{1-p}, \qquad (12)$$

$$Var[z_\infty]\equiv\lim_{t\to\infty}Var[z_t]=\frac{1}{1-(p^2+\delta^2)}\left\{\sigma^2+\frac{\mu}{1-p}\left\{p-(p^2+\delta^2)\right\}+\delta^2\left(\frac{\mu}{1-p}\right)^2\right\}. \qquad (13)$$

Therefore, the cost function based on the limiting distribution, $C_\infty^{\mathrm{DFP}}(S)$, is given as follows:

$$\begin{aligned}C_\infty^{\mathrm{DFP}}(S)&=\lim_{t\to\infty}C_t^{\mathrm{DFP}}(S)\\&=\frac{c_H+c_B}{2}\left\{\left(S-\frac{(L+1)\mu}{1-p}\right)^2+\frac{(L+1)}{1-(p^2+\delta^2)}\left\{\sigma^2+\frac{\mu}{1-p}\left\{p-(p^2+\delta^2)\right\}+\delta^2\left(\frac{\mu}{1-p}\right)^2\right\}\right\}^{\frac{1}{2}}\\&\quad+\frac{c_H-c_B}{2}\left(S-\frac{(L+1)\mu}{1-p}\right). \qquad (14)\end{aligned}$$

Further, we obtain the quasi-economical inventory policy as follows:

$$\begin{aligned}S^*&=\frac{(L+1)\mu}{1-p}+\sqrt{\frac{(c_B-c_H)^2}{4c_Hc_B}\frac{(L+1)}{1-(p^2+\delta^2)}\left\{\sigma^2+\frac{\mu}{1-p}\left\{p-(p^2+\delta^2)\right\}+\delta^2\left(\frac{\mu}{1-p}\right)^2\right\}}\\&=\frac{(L+1)\mu}{1-p}+\sqrt{\frac{(c_B-c_H)^2}{4c_Hc_B}K_1\left\{\frac{(L+1)(\sigma^2+p\mu)}{1-p^2}+K_2\right\}}, \qquad (15)\end{aligned}$$

where

$$K_1 = \frac{1-p^2}{1-\left(p^2+\delta^2\right)}, \tag{16}$$

$$K_2 = \frac{(L+1)\delta^2}{1-p^2}\left\{\left(\frac{\mu}{1-p}\right)^2 - \frac{\mu}{1-p}\right\}. \tag{17}$$

When $\delta^2 = 0$, in other words, the proportion of nonconforming items is deterministic, the quasi-economical inventory policy is given as follows:

$$S^* = \frac{(L+1)\mu}{1-p} + \sqrt{\frac{(c_B - c_H)^2}{4c_H c_B}\frac{(L+1)(\sigma^2 + p\mu)}{1-p^2}}. \tag{18}$$

From (16) and (17), K_1 and K_2 are monotonically increased as δ becomes larger. Therefore, the economical inventory policy S^* in the case that the proportion of nonconforming items is probabilistic is always larger than one in the case that the proportion of nonconforming items is deterministic.

NUMERICAL EXAMPLES

We show some numerical examples. Table 1 indicates the economical policy and some stochastic properties about the limiting distributions of z_t and r_t under the demand information $\mu = 100$ and $\sigma^2 = 10^2$. It has been conformed that S^* becomes higher as p increases from Table 1. Therefore, it has been shown from Table 1 that the inclusion of nonconforming items leads to the rise of S^*. Also, S^* becomes higher as δ increases. Note that δ doesn't influence the limit values in the expectation of z_t and r_t from (5) and (12). On one hand, δ has an influence on the limit values in the variance of z_t and r_t from (6) and (13). As the consequence, it has been conformed that the expansion in the variance of z_t and r_t due to δ brings S^* to keeping higher. Then, this result indicates that the uncertainty of the proportion of nonconforming items is one of the factors which cause the rise of S^*.

Further, we show Tables 2 and 3, where the demand information is $\mu = 200$ and $\sigma^2 = 10^2$ in Table 2 and $\mu = 100$ and $\sigma^2 = 20^2$ in Table 3, respectively. By comparing to Table 1, S^* becomes larger in Table 2 due to the change of μ. Also, S^* becomes larger in Table 3 due to the change of σ^2 with compared to Table 1. These results indicate that the change of the demand information μ and/or σ^2 is one of the factors which cause the limit values in the variance of z_t and r_t and the rise of S^*.

$p\left(\times 10^{-2}\right)$	$\delta\left(\times 10^{-2}\right)$	S^*	$E[z_\infty]$	$\sqrt{Var[z_\infty]}$	$E[r_\infty]$	$\sqrt{Var[r_\infty]}$
0.0	0.0	658.79	100.00	10.00	0.00	0.00
	0.0	665.14		10.05		1.01
1.0	1.0	665.44	101.01	10.10	1.01	1.42
	2.5	666.98		10.36		2.72
	0.0	674.92		10.13		1.60
2.5	1.0	675.23	102.56	10.18	2.56	1.90
	2.5	676.80		10.45		3.02
	0.0	691.89		10.26		2.29
5.0	1.0	692.21	105.26	10.31	5.26	2.52
	2.5	693.85		10.59		3.49

Table1: Economical inventory policy and some stochastic properties under demand information: $\mu = 100$ and $\sigma^2 = 10^2$

$p\left(\times 10^{-2}\right)$	$\delta\left(\times 10^{-2}\right)$	S^*	$E[z_\infty]$	$\sqrt{Var[z_\infty]}$	$E[r_\infty]$	$\sqrt{Var[r_\infty]}$
0.0	0.0	1258.79	200.00	10.00	0.00	0.00
	0.0	1271.50		10.10		1.42
1.0	1.0	1272.67	202.02	10.30	2.02	2.47
	2.5	1278.50		11.29		5.24
	0.0	1291.03		10.25		2.25
2.5	1.0	1292.22	205.13	10.45	5.13	3.04
	2.5	1298.14		11.46		5.60
	0.0	1324.89		10.50		3.21
5.0	1.0	1326.12	210.53	10.71	10.53	3.84
	2.5	1332.22		11.75		6.16

Table2: Economical inventory policy and some stochastic characteristics under demand information: $\mu = 200$ and $\sigma^2 = 10^2$

$p\left(\times 10^{-2}\right)$	$\delta\left(\times 10^{-2}\right)$	S^*	$E[z_\infty]$	$\sqrt{Var[z_\infty]}$	$E[r_\infty]$	$\sqrt{Var[r_\infty]}$
0.0	0.0	717.58	100.00	20.00	0.00	0.00
	0.0	723.79		20.03		1.02
1.0	1.0	723.94	101.01	20.05	1.01	1.45
	2.5	724.75		20.19		2.76
	0.0	733.36		20.07		1.66
2.5	1.0	733.52	102.56	20.10	2.56	1.96
	2.5	734.35		20.24		3.09
	0.0	750.04		20.15		2.45
5.0	1.0	750.20	105.26	20.18	5.26	2.68
	2.5	751.07		20.33		3.63

Table3: Economical inventory policy and some stochastic characteristics under demand information: $\mu = 100$ and $\sigma^2 = 20^2$

CONCLUSION

This paper has dealt with a periodic order-up-to S inventory model in the case that some nonconforming items may be included in the replenishment and the proportion of nonconforming items is probabilistic. Then, we have assumed the distribution about the demand and the proportion of nonconforming items to be unknown but those first two moments to be specified respectively. Through the distribution free procedure, we have obtained a kind of quasi-economical inventory policy. We have illustrated some numerical examples. From the result, it has been conformed that the inclusion of the nonconforming items leads to the rise of the economical inventory level. Further, the uncertainty of the proportion of nonconforming items has been also one of the factors which cause the rise of the economical inventory level. In addition, it has led to the expansion in the limit values in the variance of the order quantity and the number of nonconforming items included in the replenishment.

APPENDIX A

Using the low of total probability (Taylor and Karlin, 1998), we have obtained

$$\begin{aligned} E\left[r_t \middle| p_t\right] &= \sum_k E\left[r_t \middle| z_t = k, p_t\right] \Pr\left\{z_t = k \middle| p_t\right\} \\ &= p_t E\left[z_t \middle| p_t\right], \end{aligned}$$

$$\begin{aligned} E\left[r_t^2 \middle| p_t\right] &= \sum_k E\left[r_t^2 \middle| z_t = k, p_t\right] \Pr\left\{z_t = k \middle| p_t\right\} \\ &= p_t\left(1-p_t\right) E\left[z_t \middle| p_t\right] + p_t^2 E\left[z_t^2 \middle| p_t\right], \end{aligned}$$

and

$$\begin{aligned} Var\left[r_t \middle| p_t\right] &= E\left[r_t^2 \middle| p_t\right] - \left(E\left[r_t \middle| p_t\right]\right)^2 \\ &= p_t\left(1-p_t\right) E\left[z_t \middle| p_t\right] + p_t^2 Var\left[z_t \middle| p_t\right]. \end{aligned}$$

APPENDIX B

z_t and p_t are independent each other. Therefore, we have derived

$$\begin{aligned} E\left[r_t\right] &= \int E\left[r_t \middle| p_t\right] h\left(p_t\right) dp_t \\ &= E\left[p_t E\left[z_t \middle| p_t\right]\right] \\ &= E\left[p_t\right] E\left[z_t\right], \end{aligned}$$

$$\begin{aligned} E\left[r_t^2\right] &= \int E\left[r_t^2 \middle| p\right] h\left(p_t\right) dp_t \\ &= E\left[p_t\left(1-p_t\right) E\left[z_t \middle| p_t\right]\right] + E\left[p_t^2 E\left[z_t^2 \middle| p_t\right]\right] \\ &= E\left[p_t\left(1-p_t\right)\right] E\left[z_t\right] + E\left[p_t^2\right] E\left[z_t^2\right], \end{aligned}$$

and

$$\begin{aligned} Var\left[r_t\right] &= E\left[r_t^2\right] - \left(E\left[r_t\right]\right)^2 \\ &= E\left[p_t\left(1-p_t\right)\right] E\left[z_t\right] + E\left[p_t^2\right] E\left[z_t^2\right] - \left(E\left[p_t\right] E\left[z_t\right]\right)^2. \end{aligned}$$

APPENDIX C

From (5), (6) and (7), we have the following recursive formulas:

$$E[z_t] = E[d_{t-1}] + E[r_{t-L-1}]$$
$$= E[d_{t-1}] + E[p_{t-L-1}]E[z_{t-L-1}],$$
$$Var[z_t] = Var[d_{t-1}] + Var[r_{t-L-1}]$$
$$= Var[d_{t-1}] + E[z_{t-L-1}]\left(E[p_{t-L-1}] - E\left[p_{t-L-1}^2\right]\right) + E\left[z_{t-L-1}^2\right]E\left[p_{t-L-1}^2\right] - \left(E[p_{t-L-1}]E[z_{t-L-1}]\right)^2,$$

where $t = L+2,\cdots$. Then, by solving the recursive formulas, we obtain (8) and (9).

APPENDIX D

First, the following equations are given:

$$[x]^+ = \frac{|x|+x}{2}, \quad [x]^- = \frac{|x|-x}{2}.$$

Then, the following inequality is derived from the Cauchy-Schwarz's inequality:

$$E|x| \le \left(E\left[x^2\right]\right)^{\frac{1}{2}}.$$

From (10), we obtain

$$C_t(S) = c_H E\left[S - \sum_{i=t-L}^{t-L} z_{i+1}\right]^+ + c_B E\left[S - \sum_{i=t-L}^{t} z_{i+1}\right]^-$$
$$= \frac{c_H}{2}\left\{E\left|S - \sum_{i=t-L}^{t-L} z_{i+1}\right| + E\left[S - \sum_{i=t-L}^{t-L} z_{i+1}\right]\right\} + \frac{c_B}{2}\left\{E\left|S - \sum_{i=t-L}^{t-L} z_{i+1}\right| - E\left[S - \sum_{i=t-L}^{t-L} z_{i+1}\right]\right\}$$
$$= \frac{c_H + c_B}{2} E\left|S - \sum_{i=t-L}^{t-L} z_{i+1}\right| + \frac{c_H - c_B}{2} E\left[S - \sum_{i=t-L}^{t-L} z_{i+1}\right]$$
$$\le \frac{c_H + c_B}{2}\left\{\left(E\left[S - \sum_{i=t-L}^{t-L} z_{i+1}\right]\right)^2 + Var\left[S - \sum_{i=t-L}^{t-L} z_{i+1}\right]\right\}^{\frac{1}{2}} + \frac{c_H - c_B}{2} E\left[S - \sum_{i=t-L}^{t-L} z_{i+1}\right].$$

From (7), z_t depends on r_{t-L-1} for all t. Naturally, z_t depends on z_{t-L-1} for all t. On the other hand, z_t is independent of $z_{t-i}, i = 1,2,\cdots,L$. Therefore, the above equation is transformed into as follows:

$$C_t(S) \le \frac{c_H + c_B}{2}\left\{\left(E\left[S - \sum_{i=t-L}^{t} z_{i+1}\right]\right)^2 + Var\left[S - \sum_{i=t-L}^{t} z_{i+1}\right]\right\}^{\frac{1}{2}} + \frac{c_H - c_B}{2} E\left[S - \sum_{i=t-L}^{t} z_{i+1}\right]$$
$$= \frac{c_H + c_B}{2}\left\{\left(S - \sum_{i=t-L}^{t} E[z_{i+1}]\right)^2 + \sum_{i=t-L}^{t} Var[z_{i+1}]\right\}^{\frac{1}{2}} + \frac{c_H - c_B}{2}\left\{S - \sum_{i=t-L}^{t} E[z_{i+1}]\right\} \equiv C_t^{\mathrm{DFP}}(S).$$

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COMPARISON OF THREE POSSIBILISTIC PROGRAMMING MODELS FOR VEHICLE ROUTING PROBLEM WITH FUZZY DEMANDS

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ABSTRACT

In this paper, we deal with the vehicle routing problem where vehicles have finite capacities and demands of customers are uncertain. We represent the uncertain demands by means of fuzzy numbers and interpret them as possibility distributions. We propose three models of the problem: the first one is a expected value model, the second one is a chance-constrained model and the last one is called as two-stage model with recourse cost where the recourse cost can be considered as the penalty necessary to cope with the fuzziness in demands of customers. We discuss solution methods of these models and make a comparison to illustrate the difference of the proposed models. Through fuzzy simulation with a numerical example, it is showed that when total capacity of vehicles is tighter to total demands of customers, the optimal solution of the two-stage model is different from that of the other two models, and the optimal routing plan of the two-stage model has the lowest possibility of failure arising. A failure means that a vehicle is not able to serve some customers once it arrives there along the planned route due to insufficient capacity.

Keywords: Fuzzy Vehicle Routing, Possibilistic Programming, Recourse Cost, Scheduling

1. INTRODUCTION

Efficient fleet and vehicle planning, scheduling and dispatching are essential for transportation service providers that want to improve service and increase reactivity, particularly when cost is a primary factor. In the field of operations research, the problems of fleet and vehicle planning, scheduling and dispatching are recognized as Vehicle Routing Problems (VRP). A typical vehicle routing problem requires one to design least cost routes from one depot to a set of geographically scattered points (cities, stores, warehouses, schools, customers etc.) [1].

Although a great number of models and solution methods for solving vehicle routing problems, almost of them arise from deterministic mathematical models and all the factors involved in the models must be known exactly. Unfortunately, real world situations are often not so deterministic. There are cases that the imprecision/ uncertainty concerning demand, location, distance, timing, travel time, etc. must be taken into account.

Fuzzy set theory has provided efficient and meaningful concepts and methodologies to formulate and solve mathematical programming and decision-making problems of real world [2-3].Fuzzy approaches have been applied to solve a few kinds of fuzzy vehicle routing problems. Dubois and Prade [4] first introduced the fuzzy shortest-path problem in 1980. This problem has further been investigated by other researchers and generalized to a variety of situations

[5-7]. Cheng and Gen [8] proposed a genetic algorithm to solve the fuzzy vehicle routing problem that fuzzy due-time is given as a triangular fuzzy number and the objectives are to minimize the fleet size of vehicles, maximize the average grade of satisfaction over customers, and minimize total travel distance and total waiting time for vehicles. Dusan and Goran [9] incorporated the rules of fuzzy arithmetic and fuzzy logic into the heuristic sweeping algorithm, and proposed two approximate reasoning algorithms to solve the vehicle routing problem with fuzzy demands.

In this paper, we deal with the vehicle routing problem that vehicles have finite capacities and demands of customers are uncertain. We represent the uncertain demands by means of fuzzy numbers and interpret them as possibility distributions. We propose three possibilistic programming models for the problem, the first one is expected value model, the second one is chance-constrained model and the last one is two-stage model with recourse cost. We further show that these models are equivalent to ordinary 0-1 integer programming problems if the fuzzy demands are represented as normalized trapezoidal fuzzy numbers. To illustrate the difference of the proposed models, we will make a fuzzy simulation and investigate the frequency of failures in the case where the optimal solutions of the three models are different. A failure means that a vehicle is not able to serve some customers once it arrives there along the planned route due to insufficient capacity.

2. PROBLEM DESCRIPTION

The fuzzy vehicle routing problem considered in this paper is specified as follows:

(1) There is one central depot. m vehicles in the fleet start from the central depot, traverse n ($n > 1$) customers to pick up passengers or products, and return to the central depot. Customers are indexed from 1 to n and the index 0 stands for the central depot.

(2) The cost (distance or time, etc.) of a vehicle travelling from customer i (or depot 0) directly to customer j (or depot 0) is c_{ij}, which is an exact number and also $c_{ii}=0$ (i, j =0, 1, 2, ..., n).

(3) The capacity of vehicle k is Q_k (k =1, 2, ..., m), which is an exact number.

(4) The demands of customers cannot be known exactly. The demand of customer i is described by a normalized trapezoidal fuzzy number $\boldsymbol{D}_i$, its membership function is $\mu_{D_i}(x)$ (i =1, 2, ..., n).

(5) A picking up must be made to each customer exactly once and vehicles are always available.

(6) The objective is to find the optimal routing plan for vehicles to minimize total travelling cost.

3. EXPECTED VALUE MODEL

3.1 Notation and Formulation of Problem

We first introduce the following indices and notations:

i,j: customers (i,j =1, 2, ..., n) and i,j= 0: depot.

k : vehicles (k =1, 2, ..., m).

$$x_{kij} = \begin{cases} 1, & \text{if vehicle } k \text{ travels directly from customer } i \text{ to customer } j \\ 0, & \text{others} \end{cases}$$

R_k: total requirement of picking up for vehicle k (k =1, 2, ..., m).

Suppose the demand of customer i be a crisp number D_i instead of a fuzzy number $\boldsymbol{D}_i$, we have the following total travelling cost minimization model:

$$\text{Minimize} \quad C = \sum_{k=1}^{m}\sum_{i=0}^{n}\sum_{j=0}^{n} x_{kij} c_{ij} \tag{1}$$

Subject to

$$R_k = \sum_{i=0}^{n}\sum_{j=1}^{n} x_{kij} D_j \ ; \ k=1, 2, ..., m \tag{2}$$

$$R_k \le Q_k \ ; \ k=1, 2, ..., m \tag{3}$$

$$\sum_{k=1}^{m}\sum_{j=0}^{n} x_{kij} = 1 \ ; \ i=1, 2, ..., n \tag{4}$$

$$\sum_{j=1}^{n} x_{k0j} = 1, \quad \sum_{i=1}^{n} x_{ki0} = 1 \ ; \ k=1, 2, ..., m \tag{5}$$

$$\sum_{j=0}^{n} x_{kij} - \sum_{j=0}^{n} x_{kji} = 0 \ ; \ i=1, 2, ..., n \tag{6}$$

$$x_{kij} \in \{1, 0\} \ ; \quad i,j=0, 1, 2, ..., n; \ k=1, 2, ..., m \tag{7}$$

The objective function (1) seeks to minimize total travelling cost. Equations (2) and (3) are capacity constraints. Constraints (4) ensure that each customer will be visited by one and only one vehicle, while constraints (5) specify that each route begins and ends at the depot 0. Equation (6) is flow conservation constraints that make sure exactly one vehicle goes into and out of a customer.
Unfortunately, if the demand of customer i is a fuzzy number $\boldsymbol{D}_i$, the model of equations (1-7) does not have mathematical meaning because constraints (3) have different interpretations and do not define a crisp feasible set.

3.2 Expected Value Model and Its Solution Method

Similar to stochastic programming, a quantifiable approach is to solve the original minimization problem of equations (1-7) by replacing all the fuzzy data with their expected values. Denoting the expected value of a fuzzy variable $\boldsymbol{V}$ by E[$\boldsymbol{V}$], the Expected Value Model (EVM) of the fuzzy vehicle routing problem can be formulated as following:

$$\text{Minimize} \quad C = \sum_{k=1}^{m}\sum_{i=0}^{n}\sum_{j=0}^{n} x_{kij} c_{ij} \tag{8}$$

Subject to

$$\mathrm{E}(\boldsymbol{R}_k) = \sum_{i=0}^{n}\sum_{j=1}^{n} x_{kij}\, \mathrm{E}(\boldsymbol{D}_j) \ ; \quad k=1, 2, ..., m \tag{9}$$

$$\mathrm{E}[\boldsymbol{R}^k] \le Q^k \quad ; \quad k=1, 2, ..., m \tag{10}$$

$$\sum_{k=1}^{m}\sum_{j=0}^{n} x_{kij} = 1 \ ; \quad i=1, 2, ..., n \tag{11}$$

$$\sum_{j=1}^{n} x_{k0j} = 1, \quad \sum_{i=1}^{n} x_{ki0} = 1 \quad ; \quad k=1, 2, ..., m \tag{12}$$

$$\sum_{j=0}^{n} x_{kij} - \sum_{j=0}^{n} x_{kji} = 0 \ ; \quad i=1, 2, ..., n \tag{13}$$

$$x_{kij} \in \{1, 0\} \quad ; \quad i,j=0, 1, 2, ..., n; \ k=1, 2, ..., m \tag{14}$$

Liu [10-11] has given a definition of expected values of fuzzy variables. A trapezoidal fuzzy number $\boldsymbol{V}$= (v_a, v_b, v_c, v_d) (as shown in Figure 1) has an expected value

$$\mathrm{E}[\boldsymbol{V}] = \tfrac{1}{4}(v_a + v_b + v_c + v_d) \tag{15}$$

Denoting the trapezoidal fuzzy demand of customer i as $\boldsymbol{D}_i$ = (d_{ai}, d_{bi}, d_{ci}, d_{di})

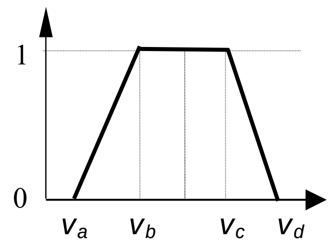

Figure 1 Trapezoidal fuzzy number $\boldsymbol{V}=(v_a, v_b, v_c, v_d)$

and the total quantity of picking up required for vehicle k as $\boldsymbol{R}_k = (r_{ak}, r_{bk}, r_{ck}, r_{dk})$, we have

$$r_{ak} = \sum_{i=0}^{n}\sum_{j=1}^{n} x_{kij} d_{aj}\ ,\quad r_{bk} = \sum_{i=0}^{n}\sum_{j=1}^{n} x_{kij} d_{bj}\ ,\quad r_{ck} = \sum_{i=0}^{n}\sum_{j=1}^{n} x_{kij} d_{cj}\ ,\quad r_{dk} = \sum_{i=0}^{n}\sum_{j=1}^{n} x_{kij} d_{dj} \qquad (16)$$

$\boldsymbol{R}_k$ has an expected value

$$\mathrm{E}[\boldsymbol{R}_k] = \frac{1}{4}(r_{ak} + r_{bk} + r_{ck} + r_{dk}) \qquad (17)$$

Substituting equation (16) for constraints (9), and equation (17) for constraints (10) respectively, constraints (10) can be rewritten as

$$\frac{1}{4}(r_{ak} + r_{bk} + r_{ck} + r_{dk}) \le Q_k \ ; \quad k=1, 2, ..., m \qquad (18)$$

As equations (16) and (18) do not include any fuzzy number, the expected value model (8-14) of the fuzzy vehicle routing problem is equivalent to an ordinary 0-1 integer programming problem.

4. CHANCE-CONSTRAINED MODEL

4.1 Chance-Constrained Model of Problem

If the demand of customer i is a fuzzy number $\boldsymbol{D}_i$, constraints $\boldsymbol{R}_k \le Q_k$ (k=1, 2, ..., m) do not define a crisp feasible set. A reasonable choice is to provide a confidence level and then find an optimal solution that the fuzzy constraints are desired to hold at the given confidence level. Thus, we have a Chance-Constraint Model (CCM) for the fuzzy vehicle routing problem as follows.

$$\text{Minimize} \quad C = \sum_{k=1}^{m}\sum_{i=0}^{n}\sum_{j=0}^{n} x_{kij} c_{ij} \qquad (19)$$

Subject to

$$\boldsymbol{R}_k = \sum_{i=0}^{n}\sum_{j=1}^{n} x_{kij} \boldsymbol{D}_j \ ; \quad k=1, 2, ..., m \qquad (20)$$

$$\mathrm{Cr}\{\boldsymbol{R}_k \le Q_k\} \ge \alpha \ ; \quad k=1, 2, ..., m \qquad (21)$$

$$\sum_{k=1}^{m}\sum_{j=0}^{n} x_{kij} = 1 \ ; \quad i=1, 2, ..., n \qquad (22)$$

$$\sum_{j=1}^{n} x_{k0j} = 1, \quad \sum_{i=1}^{n} x_{ki0} = 1 \ ; \quad k=1, 2, ..., m \qquad (23)$$

$$\sum_{j=0}^{n} x_{kij} - \sum_{j=0}^{n} x_{kji} = 0 \ ; \quad i=1, 2, ..., n \qquad (24)$$

$$x_{kij} \in \{1, 0\} \ ; \quad i,j=0, 1, 2, ..., n;\ k=1, 2, ..., m \qquad (25)$$

Here Cr{**A**} indicates the credibility measure of a fuzzy event **A**, which was defined by Liu [10-11]. α is the given confidence level at which it is desired that the fuzzy constraints hold.

4.2 Solution Method of Chance-Constrained Model

According also to the results given by Liu [10], when $\boldsymbol{R}_k$ is a trapezoidal fuzzy number $\boldsymbol{R}_k = (r_{ak}, r_{bk}, r_{ck}, r_{dk})$, fuzzy constraints (21) can be converted into their crisp equivalents as following,

(1) When $\alpha < \frac{1}{2}$, Cr $\{\boldsymbol{R}_k \le Q_k\} \ge \alpha$ if and only if

$$(1 - 2\alpha)\, r_{ak} + 2\alpha\, r_{bk} - Q_k \le 0 \;;\; k=1, 2, ..., m \tag{26}$$

(2) When $\alpha \ge \frac{1}{2}$, Cr $\{\boldsymbol{R}_k \le Q_k\} \ge \alpha$ if and only if

$$(2 - 2\alpha)\, r_{ck} + (2\alpha - 1)\, r_{dk} - Q_k \le 0 \;;\; k=1, 2, ..., m \tag{27}$$

Substituting equations (26) and (27) for constraints (21), it is clear that the chance-constraint model (19-25) of the fuzzy vehicle routing problem is also equivalent to an ordinary 0-1 integer programming problem.

5. TWO-STAGE MODEL

5.1 Recourse Cost and Two-Stage Model

Based on the same consideration as the stochastic programming with recourse [12], we can solve the fuzzy vehicle routing problem through the following two stages decision:

- At the first stage, as exact values of fuzzy demands of customers cannot be known at present, we make a decision to obtain a routing plan "here and now" before the realization of fuzzy demands is known.
- At the second stage, after the realization of fuzzy demands is known, a second decision is to be made to minimize the penalties that may appear due to any infeasibility or additional cost that is necessary to make corrections or recourse actions on the routing plan obtained at the first stage.

The penalties and the additional cost considered at the second stage are called as recourse cost. Since the recourse cost depends on the consequence of the first stage decision, the scheduling criterion is to choose a routing plan to minimize total cost, consisting of the decision cost at the first stage and the recourse cost at the second stage.

(1) Recourse cost

For the fuzzy vehicle routing problem considered here, the recourse cost is the penalty due to less utilization of vehicles' capacity and the additional cost to cover the failures that vehicles are not able to serve some customers on the planned route due to insufficient capacity. Denoting the less utilization of capacity of vehicle k by $\boldsymbol{S}_k$ and the lack of capacity of vehicle k by $\boldsymbol{L}_k$ respectively, we define $\boldsymbol{S}_k$ and $\boldsymbol{L}_k$ as:

$$\boldsymbol{S}_k = \text{Max}(0, Q_k - \boldsymbol{R}_k), \quad \boldsymbol{L}_k = \text{Max}(0, \boldsymbol{R}_k - Q_k)\;;\; k=1, 2, ..., m \tag{28}$$

Let u_k (u_k>0) be the penalty for a unit less utilization of capacity of vehicle k, and v_k (v_k>0) be the additional cost for a unit lack of capacity of vehicle k, the recourse cost can then be calculated as:

$$\sum_{k=1}^{m} [u_k \boldsymbol{S}_k + v_k \boldsymbol{L}_k] \tag{29}$$

(2) Two-Stage Model

For each possible realization of fuzzy demands, we can decide a correction or a recourse action of the minimum recourse cost; weighted with their respective possibilities, a mean cost can be computed. This mean cost is indeed the mean recourse cost corresponding to all of routing plan obtained at the first stage. The criterion to choose a routing plan thus becomes the minimal total cost, consisting of the direct cost in the first stage and the mean recourse cost at the second stage. We propose Two-Stage Model (TSM) for the fuzzy vehicle routing problem as follows.

$$\text{Minimize} \quad C = \sum_{k=1}^{m}\sum_{i=0}^{n}\sum_{j=0}^{n} x_{kij}c_{ij} + \mathrm{E}\left(\sum_{k=1}^{m}[u_k \boldsymbol{S}_k + v_k \boldsymbol{L}_k]\right) \tag{30}$$

Subject to

$$\boldsymbol{R}_k = \sum_{i=0}^{n}\sum_{j=1}^{n} x_{kij}\boldsymbol{D}_j \quad ; \quad k=1, 2, ..., m \tag{31}$$

$$\boldsymbol{S}_k = \mathrm{Max}(0, Q_k - \boldsymbol{R}_k), \quad \boldsymbol{L}_k = \mathrm{Max}(0, \boldsymbol{R}_k - Q_k) \; ; \; k=1, 2, ..., m \tag{32}$$

$$\sum_{k=1}^{m}\sum_{j=0}^{n} x_{kij} = 1 \quad ; \quad i=1, 2, ..., n \tag{33}$$

$$\sum_{j=1}^{n} x_{k0j} = 1, \quad \sum_{i=1}^{n} x_{ki0} = 1 \quad ; \quad k=1, 2, ..., m \tag{34}$$

$$\sum_{j=0}^{n} x_{kij} - \sum_{j=0}^{n} x_{kji} = 0 \quad ; \quad i=1, 2, ..., n \tag{35}$$

$$x_{kij} \in \{1, 0\} \quad ; \quad i,j=0, 1, 2, ..., n; \; k=1, 2, ..., m \tag{36}$$

5.2 Solution Method of Two-Stage Model

Though $\boldsymbol{D}_i$ and $\boldsymbol{R}_k$ are normalized trapezoidal fuzzy numbers, $\boldsymbol{S}_k$ and $\boldsymbol{L}_k$ are calculated using the "max" operator as shown in equation (32), and generally they are not normalized trapezoidal fuzzy numbers. It is necessary to calculate expected values of non-normalized trapezoidal fuzzy numbers.

Let $\boldsymbol{V}$ be a normalized trapezoidal fuzzy number $\boldsymbol{V}= (v_a, v_b, v_c, v_d)$ and $\boldsymbol{U}= \max(0, \boldsymbol{V})$, the expected value $\mathrm{E}[\boldsymbol{U}]$ of $\boldsymbol{U}$ can be calculated as the following equation (37) according to the definition of expected values given by Liu [10-11].

$$\mathrm{E}[\boldsymbol{U}] = \begin{cases} 0 & ; \quad v_d \le 0 \\ \dfrac{v_d^2}{4(v_d - v_c)} & ; \quad v_c \le 0, v_d > 0 \\ \frac{1}{4}(v_c + v_d) & ; \quad v_b \le 0, v_c > 0 \\ \frac{1}{4}\left(\dfrac{v_a\, v_b}{v_b - v_a} + v_b + v_c + v_d\right) & ; \quad v_a \le 0, v_b > 0 \\ \frac{1}{4}(v_a + v_b + v_c + v_d) & ; \quad v_a > 0 \end{cases} \tag{37}$$

Note that objective (30) can also be rewritten as:

$$\text{Minimize} \quad C = \sum_{k=1}^{m}\sum_{i=0}^{n}\sum_{j=0}^{n} x_{kij}c_{ij} + \sum_{k=1}^{m}[u_k\, \mathrm{E}(\boldsymbol{S}_k) + v_k\, \mathrm{E}(\boldsymbol{L}_k)] \tag{38}$$

Then the objective value (30) can be calculated according to equation (37), and the two-stage model (30-36) of the fuzzy vehicle routing problem reduces to an ordinary 0-1 integer programming problem.

6. COMPARISON THROUGH FUZZY SIMULATION

6.1 Numerical Example and its solutions

To compare the three models proposed above, we consider an example of 3-customer and 2-vehicle fuzzy vehicle routing problem. The direct cost between every two customers or depot and the trapezoidal fuzzy demands of customers are generated randomly from some uniform discrete distributions. Table 1 shows the direct costs and the fuzzy demands.

We also choose the confidence level α of equation (21) as $\alpha = 0.7$, weights in the objection function of equation (30) or (38) as $u_k=1.0$, $v_k = 40.0$ ($k=1, 2$).

Table 1 Direct cost and fuzzy demands

Direct cost between customers or depot					Demand	
Customer No	0	1	2	3	Customer No	Demand
0	0	25	130	138	0	(0, 0, 0, 0)
1	25	0	104	115	1	(9, 12, 15, 24)
2	130	104	0	52	2	(50, 64, 76, 88)
3	138	115	52	0	3	(48, 62, 83, 95)

Applying the enumerating method to obtain the problem solutions, we generate all of possible routing plans for customers and evaluate the corresponding objective values for the three proposed models. Table 2 shows routing plans and the corresponding objective values. If a routing plan can not satisfy capacity constraints, it is not a feasible solution, denoted as “NG” in Table 2.

Table 2 Routing plans and their objective values

Routing plan of vehicles			$Q_1=120,\ Q_2=120$			$Q_1=90,\ Q_2=120$			$Q_1=70,\ Q_2=90$		
No	Vehicle 1	Vehicle 2	EVM	CCM	TSM	EVM	CCM	TSM	EVM	CCM	TSM
1	$0\to1\to2\to3\to0$	0	NG	NG	1835	NG	NG	2979	NG	NG	3779
2	$0\to1\to3\to2\to0$	0	NG	NG	1838	NG	NG	2982	NG	NG	3782
3	$0\to2\to1\to3\to0$	0	NG	NG	2003	NG	NG	3147	NG	NG	3947
4	$0\to1\to2\to0$	$0\to3\to0$	535	535	619	535	NG	824	NG	NG	1227
5	$0\to1\to3\to0$	$0\to2\to0$	538	538	622	538	NG	971	NG	NG	1340
6	$0\to2\to3\to0$	$0\to1\to0$	NG	NG	1512	NG	NG	2535	NG	NG	3305
7	$0\to1\to0$	$0\to2\to3\to0$	NG	NG	1512	NG	NG	1482	NG	NG	2485
8	$0\to2\to0$	$0\to1\to3\to0$	538	538	622	538	538	592	538	NG	1167
9	$0\to3\to0$	$0\to1\to2\to0$	535	535	619	535	535	610	NG	NG	1164
10	0	$0\to1\to2\to3\to0$	NG	NG	1835	NG	NG	1835	NG	NG	2979
11	0	$0\to1\to3\to2\to0$	NG	NG	1838	NG	NG	1838	NG	NG	2982
12	0	$0\to2\to1\to3\to0$	NG	NG	2003	NG	NG	2003	NG	NG	3147

From computational results shown in Table 2, we observed that:

(1) If we do not consider capacity constraints of vehicles, the optimal routing plan is Routing Plan No.1 or No.10, and the minimum total travelling cost is 319. It is easy to understand that the optimal routing plan changes to others if capacity constraints of vehicles are taken into account.

(2) If total capacity of vehicles has larger surplus to total demands of customers, the same optimal solution is obtained through the three models.

(3) When total capacity of vehicles gets tighter to total demands of customers, the optimal solution of the two-stage model is different from that of the other two models.

(4) Among the three models, the chance-constrained model provides a very tight constraint to capacity of vehicles, and it has very few feasible solutions compared to the other two models. On the other hand, the two-stage model has no infeasible solution because non-satisfaction of the capacity constraints is taken into the objective value as recourse costs.

6.2 Frequency of Failures

To illustrate further the difference of the three models proposed above, we investigate the frequency of failures in the case where the optimal solutions of the three models are different. A failure means that a vehicle is not able to serve a customer once it arrives there along the planned route due to insufficient capacity. We make the investigation through fuzzy simulation as the following procedure.

[Step1] Generate a demand for every vehicle according to its possibilistic distribution.

[Step2] Calculate the total requirement for every vehicle along the given routing plan.

[Step3] If the total requirement of a vehicle is larger than its capacity, then a failure occurs and counts to the number of failures.

[Step4] Repeat step 1-3 until the maximum number of simulation experiments is reached.

Let the maximum number of simulation experiments equal 10000, the frequency of failures for the solutions in the case where Q_1=90 and Q_2=120 is obtained and shown in Table3.

Table 3 Frequency of failures (Q_1=90, Q_2=120, 10000 simulation experiments)

Routing plan of vehicles			Model	Frequency of failures	
No	Vehicle 1	Vehicle 2			
4	0→1→2→0	0→3→0	EVM	2,967	29.67%
8	0→2→0	0→1→3→0	TSM	0	0%
9	0→3→0	0→1→2→0	EVM, CCM	338	3.38%

The results of Table 3 showed that the failure occurs at a frequency of 29.67% if the Routing plan No.4 is executed, which is the optimal solution of the expected value model. Since no failure occurs along the Routing plan No.8 that is the optimal solution of the two-stage model, the optimal routing plan of the two-stage model is superior to that of other models.

In the case where Q_1=70 and Q_2=90, the frequency of failures along Routing plan No.8 and No.9 is also obtained through 10000 simulation experiments and shown in Table 4. From Table 4, it is obvious that the optimal routing plan of the two-stage model is not inferior to that of other models.

Table 4 Frequency of failures (Q_1=70, Q_2=90, 10000 simulation experiments)

Routing plan of vehicles			Model	Frequency of failures	
No	Vehicle 1	Vehicle 2			
8	0→2→0	0→1→3→0	EVM	6,966	69.66%
9	0→3→0	0→1→2→0	TSM	6,897	68.97%

7. CONCLUDING REMARKS

For those situations when the manager cannot exactly specify demands of customers as either deterministic numbers or probabilistic random variables, it is natural and realistic to express the demands as fuzzy numbers. In this study, we dealt with the vehicle routing problem with fuzzy demands and proposed three possibilistic programming models for the problem. Through fuzzy simulation with a numerical example, we have shown that:

(1) Compared to the expected value model and the two-stage model, the chance-constrained model provides the tightest constraints to the capacities of vehicles and it has very few feasible solutions.

(2) As the two-stage model treats the influence of fuzziness in customers' demands as recourse cost and adds the recourse cost to the objective value, it is essentially equivalent to an ordinary 0-1 integer programming problem without capacity constraints, and thus has a computational advantage over the other two models.

(3) The optimal routing plan of the two-stage model is superior or not inferior to

that of other models in the frequency of failures. Therefore, the optimal routing plan of the two-stage model has the lowest possibility that a failure occurs.

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AGENT-BASED MODEL FOR OPTIMISING SUPPLY CHAIN CONFIGURATIONS

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ABSTRACT

This paper presents an agent-based approach for modelling manufacturing supply chains with alternative resource options and optimising chain configurations in response to demand changes across product mixes. With this approach, a manufacturing supply chain with alternative resource options is modelled using a multi-agent architecture. Agents representing resources in the supply chain interact iteratively with agents handling customer orders under the control of a genetic algorithm to find the most favourable configurations of resources to fulfil individual orders with minimum total supply chain cost. This approach is used to build a supply chain simulation platform, where a desirable supply chain configuration that could cope with future customer orders over a period of time without having the chain reconfigured for every order, can be identified by processing a forecast sequence of customer orders using the approach and identifying the most commonly used resource set.

KEYWORDS: Supply Chain, Agents, Configuration, Optimisation, Iterative Bidding.

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INTRODUCTION

A manufacturing supply chain consists of a number of autonomous or semi-autonomous business organisations that are collectively responsible for performing a variety of functions associated with meeting orders placed by customers. The supply chain can be viewed as a network with nodes representing various organisations/resources and the services they provide to satisfy customers orders within specified time intervals. Usually, there may be several resource options available at the nodes of the supply network and these are often differentiated by their individual costs and lead-times. With a variety of resource alternatives and complex, often institutional, constraints such as uncertainties in cost and supplier performances and variations in trust and commitment between partners, a core challenge to manufacturing organisations is how to effectively optimise the configuration of their supply chains such that customer orders are duly satisfied across a mix of products while costs are kept to the minimum. Although a completely dynamic supply chain, where the best combination of resources is found and used for every customer order, may be desirable in certain situations (Choy et al., 2001; D'Amours et al., 1996), many organisations prefer to have a relatively stable supply chain configuration that evolves over time with respect to changes in demand across products. In effect, formation of strategic alliances within manufacturing supply chains requires certain level of trust and commitment. Factors such as risk liability, behavioural uncertainty, information sharing and cost/service tradeoffs influence the levels of trust and commitment within organisations. Lead-time uncertainty, foreign exchange rates and organisational culture are other factors that affect formation and sustenance of a stable manufacturing supply chain configuration. The question is, in spite of the constraints on formation of strategic alliances, how do manufacturing organisations identify an optimal supply chain configuration that will cater for customer orders over a period of time while continuously monitoring patterns of changes in demand to identify the need and options for next chain reconfiguration.

This paper presents an agent-based approach for modelling supply chains with alternative resource options and generating optimal chain configurations in response to demand changes across product mixes. The concept is to represent a manufacturing supply chain as a multi-agent architecture with agents representing resources and exhibiting their behaviours and functionalities. In addition, the functions of order handling, operation controlling and communication facilitating within the chain are also modelled as agents. Agents in the architecture interact iteratively with one another under the control of a genetic algorithm to find the most favourable configurations of resources to fulfil individual customer orders with minimum total supply chain cost. Such interactions include the identification and sourcing of suitable and reliable resources to perform required operations for customer orders by the order handling agents and the competing for the tasks of performing required operations by individual resource agents. This approach is used to build a supply chain simulation platform, where a desirable supply chain configuration that could cope with future customer orders over a period of time without having the chain reconfigured for every order, can be identified by processing a forecast sequence of customer orders using the approach and identifying the most commonly used resource set.

The paper is structured as follows. The literature review section provides some background into literature concerned with the optimisation of supply chain configurations. The problem representation section illustrates the representation of a manufacturing supply chain problem. The following sections discuss the proposed approach to solving the problem and implementation of the approach respectively. The penultimate section presents a test case as well as computational results. We conclude in the final section and identify directions for future research.

LITERATURE REVIEW

Deciding on how to configure and optimise supply chains is a problem that has been tackled by academic and industrial researchers. Contributions have been made using models ranging from mathematical and operational research to systems modelling and simulation. Supply chain modelling approaches can be classified into analytical and simulation models. Analytical models which involve mathematical optimisation techniques have proven useful in many cases, but they are often too simplistic to be of practical use for complex supply chain problems (Hung et al., 2006). Simulation models on the other hand, can capture realistic supply chain characteristics; provided the modeller is able to effectively construe these characteristics into the simulation environment.

Several proposed models in literature configure supply chains based on cost as the sole decision variable while some include performance measurements such as delivery reliability, quality and responsiveness (Cakravastia et al., 2002; Garavelli, 2003; Wu and O'Grady, 2004). The mixed-integer programming model proposed by Cakravastia et al. (2002) focussed on minimising customer dissatisfaction in terms of cost and lead-time by evaluating the supply chain at two levels. The first level involves optimising the manufacturing and logistical activities of each supplier and the second level is at the chain level whereby bids from all suppliers are evaluated before the supply chain is configured.

In addition to direct manufacturing costs, some mathematical approaches consider costs of distribution and holding safety-stock in their supply chain cost minimisation problems (Huang et al., 2005; Graves and Willems, 2001). Huang et al. (2005) used genetic algorithm to address the challenge of how to generate optimal configuration of products, manufacturing processes and supply sources in a simultaneous and integrated manner. Their approach looked at how configuration can be achieved for a product platform having component commonalities and the optimal level of safety stock to hold in inventory. Graves and Willems (2001) on the other hand utilised dynamic programming to solve the same configuration problem, with emphasis on strategic stock placement along the supply chain.

However, mathematical and optimisation models are still a challenge to operations research in that the complication of the problem is beyond finding optimal total costs but also involves time series and structural stability decisions (Wang et al., 2001). In the area of simulation and systems modelling, researchers have addressed supply chain configuration problems by considering virtual enterprises to manage orders (Chen et al., 1999; Li & Fong, 2003; Choy et al., 2001; Petersen et al., 2001). In particular, the model proposed by Chen et al. (1999) places the supply chain in a dynamic environment such that depending on product and customer specifications, a virtual supply chain can be formed consisting of flexible and fixed members each time an order is placed. On the down side, the natures of some of these virtual enterprises are such that the supply chain is re-configured to suit every product order. With regards to systems modelling, expert systems have been developed and multi-agent systems have proven popular in modelling and optimising supply chain structures (Chan and Chan, 2004; Jiao et al., 2006). Gjerdrum et al. (2001) show how expert systems for distributed decision-making can be combined with contemporary numerical optimisation techniques for supply chain optimisation. They used numerical optimisation to determine optimal manufacturing schedules for factories and multi-agent systems to determine enterprise-wise tactical decisions based on information communicated between agents. Their agent-based model covers the right hand side of the supply chain from the manufacturer to the downstream customer and does not quite capture the complexity of entire supply chain partner selection.

Invariably, customer orders are the primary focus of any supply chain and it is in the interest of manufacturing organisations to have an adaptable supply chain to handle variations in product types and/or demand quantities but to have to re-configure their supply chain to accommodate each product order would prove rather inefficient in the long run.

Although, some of the mentioned approaches are deemed suitable in selecting resources by considering various costs and order-focussed virtual enterprises, issues such as flexibility of the configured supply chain to handle multiple orders across a product mix over some period as well as considerations for the reliability of the network with respect to meeting order due dates have not been adequately addressed.

PROBLEM REPRESENTATION

The objective of a manufacturing supply chain is to satisfy end-customers' product orders within promised delivery times and at the minimum possible cost. Although a completely dynamic supply chain, where the best combination of resources is found and used for every customer order, may be desirable in certain situations, many organisations prefer to have a relatively stable supply chain configuration that evolves over time with respect to changes in demand across products. A typical supply chain is comprised of a generic set of resources including suppliers, retailers, plants, warehouses, distribution centres, and transportation resources, organised into tiers. Figure 1 shows a supply chain with five tiers. The manufacturer tier represents the end-manufacturer who produces the final products for customers. There are a number of optional assembly plants in this tier that are available for producing the final products. On the immediate left side of the manufacturer tier are the first tier suppliers to the manufacturer who produce components/subassemblies used in the final products. Likewise, there are a number of optional suppliers for each of the components or subassemblies required by the manufacturer. Similarly, to the left side of the first tier suppliers are the second tier suppliers who provide components used by the first tier suppliers, and for each component there are a number of alternative suppliers. To the right hand side of the manufacturer, there are a number of optional means for transporting the finished products to customers, each having a number of optional suppliers. Finally, at the right-most part of the chain there are customers who receive the final products.

[Insert Figure 1 here]

The problem involved in satisfying a customer order is to choose the optimum set of resources, including suppliers for each components, the assembly plant, and the transportation options so that the product is manufactured and delivered to customer within a specified due date at minimal total cost.
Mathematically, this is an optimisation problem in which the objective function is the total supply chain cost for each order which includes the cost of components and subassemblies, the cost of manufacturing/assembling the final products, and that of transportation. The total time involved in getting components delivered to the chosen plant, having the final products manufactured/assembled at the plant, and delivering the finished products to the customer is the lead time for delivery which must be shorter than that specified by the due date for the order. This is

therefore a constraint to the optimisation problem. In this work, we consider an assemble-to-order production system, therefore, the costs of inventory holding for both safety stock and pipeline stock are not considered.

To illustrate this problem further with mathematical notations, we consider a simple network, as shown in Figure 2 which is used to produce two types of products shown in Figure 3 with required components and operations for each. The example is drawn from Huang et al., (2005). The two types of products involved are named Laptop-CD and Laptop-DVD. The former is sold in both the US and European markets while the latter is sold in the US market only. The two products require similar components and sub-assemblies until a point of differentiation where either a CD-RW drive or a DVD drive is included. For each product, four types of components are used to produce a circuit board assembly, which is then assembled together with a LCD display, a metal housing, a battery, and other miscellaneous components to produce a laptop subassembly. This is then integrated with either a CD-RW or a DVD drive to make up the final product.

[Insert Figure 2 here]

[Insert Figure 3 here]

The supply chain consists of 6 tiers. The manufacturer tier consists of two assembly plants ($P_{13,1}$ and $P_{14,1}$), one used to assemble Laptop-CD and the other Laptop-DVD. There are no alternative plants available at this tier for each of the products. To the left of the manufacturing tier are the first tier suppliers. There are two optional suppliers who produce the laptop subassembly, two optional suppliers who providing CD-RW drive, and two providing DVD drive. Further left, there are second tier suppliers including two optional suppliers producing the circuit board assembly, two producing LCD display, two providing metal housing, and one providing miscellaneous components. The left-most of the chain consists of four, three, two, and one optional suppliers for providing parts type 1, 2, 3, and 4 required by the circuit board assembly respectively. The transport options and customers are shown to the right of the manufacturer. In Figure 3, the parts and operations required to fulfil customer orders for the two products involved are sequenced with numbers from 1 to 17. The resources are labelled as follows. *S* represents parts suppliers, *P* assembly plants, and *T* transport options. The first number in the subscript of a resource label represents the sequence number of the parts/operation the resource provides, and the second number indexes the options.

The cost incurred in fulfilling a customer order would involve the cost of each part sourced from an optional supplier, the cost of assembly from an optional plant for each assembly operation required, and the cost of delivery by a transport option. Denote C_{ij} as the cost of part *i* supplied by supplier S_{ij} (or the cost of assembly operation *i* performed by plant P_{ij}, or that of transportation activity *i* provided by transport option T_{ij}), X_i as a variable indicating whether part/operation *i* is required by a product order ($X_i = 0$ if the part/operation is not required by an order, and 1 if it is required), and y_{ij} as a variable indicating whether resource S_{ij} (or P_{ij}, or T_{ij}) is selected to provide part *i* (or perform operation *i*), $y_{ij} = 0$ if the resource is not selected and 1 if it is selected. The total supply chain cost for satisfying the order will be:

$$SCC = \sum_{i=1}^{17} X_i . C_i \qquad \textbf{(1)}$$

where C_i is the cost of part/operation *i*, and

$$C_i = \sum_{j=1}^{N_i} C_{ij} . y_{ij} \qquad \textbf{(2)}$$

where N_i is the number of optional resources for part/operation *i*.

Likewise, the time required to fulfil a customer order would involve the lead-time for delivery of each sourced part (i.e., from the time of placing the order to the time of receiving the part), the lead time for assembling a sub-assembly (from when parts are received) and delivering to the next stage, the lead time of final assembly, and the lead time for transporting the product to the customer. The assumption here is that for the assembly plants, orders for parts/subassemblies are placed to suppliers as soon as a part/product order is received from a downstream resource or customer. Given the lead-time t_{ij} for resource S_{ij} (or P_{ij}, T_{ij}) to provide part/operation i, as defined above, the lead time of part/operation i will be:

$$t_i = \sum_{j=1}^{N_i} y_{ij}.t_{ij} \tag{3}$$

The total time to fulfil a customer order will be:

$$t = \max(t_L, X_i t_i, i = 11{,}12) + \sum_{i=13}^{17} X_i t_i \tag{4}$$

Where t_L is the lead-time for producing and delivering the laptop subassembly to the final assembly plants.

$$t_L = \max(t_{CB}, t_i, i = 6, 7, \ldots, 9) + t_{10} \tag{5}$$

Where t_{CB} is the lead-time for producing and delivering the circuit board assembly to the next downstream stage.

$$t_{CB} = \max(t_i), i = 1, 2, \ldots, 4 \tag{6}$$

The optimisation problem is therefore to find the values of y_{ij} (i.e, choose the resource options) to minimise the total supply chain cost *SCC* for a customer order while the making sure the order due date is satisfied. Given the customer specified delivery lead time D, the constraint for the problem is:

$$t \le D \tag{7}$$

Prior to discussing the intricacies of the model, we highlight certain assumptions made in order to capture the behaviour of the supply chain system: (a) Orders arriving at each node of the supply chain are processed in a First-In, First-Out (FIFO) manner (b) lead-times of all parts/operations are deterministic (c) Capacity is not restricted at the supplier and assembly plant stages (d) assembly lead-time includes set-up and change-over times (e) costs used in the model are encompassing i.e. they include all support costs such as labour and transportation to the next stage (f) production system considered in this model is assemble-to-order, hence inventory holding is not considered.

THE PROPOSED APPROACH TO SOLVING THE PROBLEM

The problem presented in section 3 is a complicated combinatorial optimisation problem, particularly when a large number of suppliers are involved at multiple tiers and when products are of complex hierarchy involving a large number of parts. This presents a challenge to traditional dynamic programming and optimisation methods. The problem will be even more difficult to resolve when institutional constraints are present which lead to uncertainties in lead time and cost. Multi-agent systems offer both the potential of solving such large complex problems in a distributed manner and the flexibility to cope with uncertainties (Anosike and Zhang, 2006).

A multi-agent system (MAS) refers to a collection of autonomous or semi-autonomous agents operating within an environment to directly achieve their individual goals and indirectly contribute to the overall objective of the system. In general, a system that exists must be situated within an environment. Furthermore, the characteristics and interactions of the system's elements enormously contribute to the behaviour of that system. In the case of a multi-agent system, the environment is a computational environment and agents within the system must have the ability to interact with one another as well as with their environment in order to support the cause for which the system exists. Stone and Veloso (2000) highlighted some attributes of MAS that render it appropriate for modelling systems such as supply chains. Some of these include the suitability of MAS for (a) domains that comprise of components with different (or possibly conflicting) goals and propriety information, (b) systems that support parallel computation whereby the system can be broken down into several independent components and (c) systems whose particular capabilities and parameters are likely to change over time or across agents. In addition, the works of researchers such as (Swaminathan et al., 1998; Sadeh et al., 1999; Zeng and Sycara, 1999; Bo and Zhiming, 2003) support the suitability of MAS for the development of organisational structures, problem solution strategies, as well as cooperation mechanisms for a range of distributed knowledge-based problem-solving modules (Jiao et al., 2006, Brenner et al., 1998).

A supply chain can be represented as a multi-agent system whereby the organisations integrated in the chain are modelled as intelligent agents. Each agent has the qualities and functionalities of the resource they represent hence; the agents have individual goals of performing tasks such as supply of parts, assembly and transportation operations at profitable rates while working with other agents in the community to achieve the common goal of satisfying customer orders. In essence, a multi-agent model captures the purpose and dynamics of the supply chain and emulates the interactions and relationships between resources. These interactions however, affect the performance and reliability of the supply chain as a whole. The manner in which agents integrated in a supply chain coordinate their activities such that orders are satisfied within specified due dates and at minimal costs across a product mix is the core challenge addressed in this paper.

The agent-based framework

In the proposed framework, a manufacturing supply chain is represented as an agent-based model with agents representing resources and exhibiting their behaviours and functionalities. In addition, the functions of order handling, operation controlling and communication facilitating within the chain are also modelled as agents. Agents in the architecture interact iteratively with one another under the control of a genetic algorithm to find the most favourable configuration of resources to fulfil customer orders with minimum total supply chain cost.

The architecture of each of the individual agents used in the framework is shown in Figure 4. The architecture consists of a communication module, a set of control mechanisms and knowledge base (KB). The communication module contains the agent communication protocol which in this model is, the Knowledge Query Manipulation Language (KQML). Contained in the control mechanism are instructions on implementation of actions and timing system. An agent's knowledge base is its soul as it bears all information regarding the state, characteristics and capabilities of the agent. It contains the agent's task knowledge, problem-solving knowledge and co-operative knowledge. Whereas, the problem-solving knowledge covers how the agent executes its task, the co-operative knowledge contains negotiation mechanism and agent-co-ordination protocols. The common environment primarily consists of all agents in the system and a universal database that stores general information such as product details which include bill of materials and required operations, all resources; their capabilities and locations as well as any supply chain configurations achieved.

[Insert Figure 4 here]

The multi-agent framework is shown in Figure 5. It consists of a product agent, a process agent, a facilitator agent and a number of resource agents. Resource agents refer to the collection of agents that represent resources and comprise of supplier agents, plant agents and transportation agents corresponding to suppliers, assembly plants and transportation modes of the supply chain respectively. The resource agents are grouped into communities based on their functions.

[Insert Figure 5 here]

When customer orders enter the multi-agent supply chain system, they are decomposed into required parts/operations by the product agent (according to bills of materials) and forwarded to the process agent who sources for resource agents to provide the parts or perform the operations. The product agent has two primary functions; handling and decomposition of orders into required parts/operations and evaluation of identified supply chain configurations to check if lead-time requirements are satisfied and what is the total cost. The process agent maintains a list of operations required to satisfy each order and sources for suitable resources to perform the operations according to the required precedence relationships between operations. The final agent in the architecture is the facilitator agent who acts as a communication overseer and ensures a smooth flow of information between resource agents and the process agent. The facilitator agent registers as a listener with every agent and all agents in the system also register as listeners with the facilitator agent.

Proposed solution to the problem

The problem that needs to be resolved here is a typical job assignment problem, where a job consisting of *N* tasks to be completed according a predefined sequence (as defined by the product structure) is assigned to a pool of *M* resources so that a due date for the job is satisfied at the minimum cost. For each task, there is a subset of optional resources that have the technical ability to carry out the operation. It is also possible that a resource may be able to carry out more than one task on the sequence. Moreover, the resources are connected to each other by an input-output relationship (such as the supplier-customer relationship) which place constraints on whether a resource can be assigned with a particular task or not. As there are transportation of materials between successive resources, the cost and lead time for a resource to carry out a particular task vary depending on which resource will take the next task. The maximal number of resource choices in this problem is of the order m^n, which grows exponentially with the number of tasks in the job. With cost and lead time uncertainties for each resource, this number of possible combinations can go theoretically infinite. With the proposed multi-agent model, task assignment may be carried out using a bidding process where optional resources bid for tasks they are able to perform within the available constraints. The problem is that if tasks are bid for one by one according to the sequence, and resources chosen based on cost or time criterion, the resulting combination of resources can not guarantee to meet the overall due date constraint, or conduct the job with minimum cost. In order to solve this problem, we propose a coordinated iterative bidding process, where the optimal combination of resources for the job is found through a number of iterations. A set of control parameters are introduced to coordinate the bidding process within each iteration, the value of which will have a direct influence on the decisions of individual resources in bidding for tasks and will have an effect on the bidding results. The values of the control parameters are then adjusted iteratively, with a

Genetic Algorithm, to find better and better combinations. The control parameters used in the proposed method include a set of virtual prices, one corresponding to each task in the job, and a set of minimal virtual profits (that need to be made from each bid), one corresponding to each resource. With this approach, at a particular iteration, when a number of optional resources bid for a particular task J_i with a virtual price P_i, each resource calculates the virtual profit that can be made from the task, which is the difference between the virtual price and the cost to carry out the task. The resource will submit a bid for the task only if the resulting virtual profit is greater than its minimum virtual profit specified (which is another control parameter). The resulting bids for the task is evaluated and the successful bid is chosen based on time criterion, i.e., with shortest lead-time. Once all tasks have been bid for, the successful resources form a combination and the combined performance for the job, in terms of total actual cost and lead-time, are evaluated. Based on the evaluation, virtual prices across tasks and minimum virtual profits across resources are adjusted for the next iteration of bidding so that a better resource combination might arise. The total lead-time and cost of a resource combination resulting from a bidding iteration are dependent on values set for virtual prices and for minimal virtual profits. Higher virtual prices for tasks increase the attractiveness of the tasks to resources and encourage resources to submit more bids for the tasks (even though some bids may bear high costs), making it more likely to find a combination to meet the due date. Lower virtual prices on the other hand reduces the attractiveness of tasks to resources and discourage resources from submitting high cost bids for the tasks, making it more likely to find a combination that gives a low cost. Likewise, a higher level of minimal virtual profit set for a resource discourages the resource from submitting bids for tasks and a lower level encourages the resource to submit bids. Thus, if the due date is not satisfied, the virtual prices for operations could be increased and levels of minimal virtual profits for resources reduced for the next iteration to encourage resources to submit more bids. On the other hand, if the due date is satisfied, the virtual prices could be decreased and minimal virtual profits raised to discourage higher cost bids from being submitted in the next iteration, so that a lower cost combination may result. The iterative loop stops when a near optimum combination that satisfies the due date with near minimum cost is found. The coordination method is inspired by the economic model of human society. A society consists of individuals/organisations working towards their own objectives while participating in various economic activities. The society has global goals for development. In order for the global goals to be achieved, the behaviour of individuals/organisations need to be regulated by setting and adjusting tax rates, interest rates, rules and policies. In this analogy, the local goal for each resource is to make as much profit as possible by trying to find profitable bids to take part in every possible operation. The global goal for the supply chain (i.e., the process agent) is to find a collective bid that meets order due date with minimum cost. The virtual prices for operations and minimal profits for resources act as regulators for the bidding process so that the collective goal for the process agent is achieved while each resource agent achieves its local goal. The problem is how to tune the regulators so that the system could produce better and better plans over iterations.

Genetic algorithm for tuning the control parameters

Optimisation techniques, such as Tabu search and simulated annealing, could be used for tuning the parameters. This work uses a method based on Genetic Algorithms (GA). Like all GA applications, the basic building blocks are chromosomes representing potential solutions and fitness function for evaluating the fitness of each chromosome. The optimisation problem is to find a set of virtual prices and minimal virtual profits which, once used to coordinate the bidding process, will result in a resource combination for the job that satisfies the due date with minimal cost. A chromosome is thus represented by a vector composed of a full set of virtual prices and minimal virtual profits. The function to evaluate the fitness is the cost function of the resulting resource combination from bidding. A constraint to the problem is that the lead-time of the combination should also be shorter than or equal to the due date. The optimisation loop starts from the generation of an initial population of Y feasible chromosomes. This initial population is generated through a random process where a virtual price or minimum virtual profit is a random value in the range of $[0, K]$. K is a limiting value which can be set to any value greater than the total cost of any job processed by the resource pool. The generation of the initial population also considers the feasibility of chromosomes in producing a resource combination that satisfies due date. The randomly generated chromosomes are tested using the bidding process. If a chromosome does not result in a resource combination for the job which meets the due date, the chromosome is discarded and a new one generated. This process repeats until a total of Y feasible chromosomes are available in the population. The population are then put through an iterative process of reproduction involving genetic operators to find better and better chromosomes. Within each iteration, randomly selected chromosomes are subjected to genetic operations to produce new off-spring chromosomes. Each new chromosome is then used to coordinate the bidding process, resulting in a new resource combination for the job. If the new combination is better than any of those resulting from original chromosomes used to create the new chromosome, i.e., the new combination satisfies the product due date with lower cost, the new chromosome replaces the original. At the end of the reproduction process, a new generation of chromosomes are formed. This process iterates for a pre-determined number of generations or until the cost of job can no longer be improved. Both cross-over and mutation are used as genetic operators. For cross-over, chromosomes are randomly selected by a cross-over probability p_{cro} and three operators, point-to-point, single cut-off point, and dual cut-off points are used alternatively on every pair of selected chromosomes until two off-spring chromosomes, different from the parents, are created. For mutation, chromosomes are randomly selected based on a mutation probability p_{mut} and the mutation operator $P^{(new)}_{yi}=(1+\mu)P_{yi}$, where μ is a randomly generated mutation factor in a given range, is applied to a randomly selected element (mutation point) of each chosen chromosome. It should be noted that although GA is a centralised problem solving method, it is used here to optimise parameters that are used to coordinate the distributed bidding process between local units from which a collective resource combination results. The solution to the supply chain configuration problem results from local hierarchical bidding, rather than from direct centralised optimisation. The solution to the supply chain problem does not require a mathematical model of the system and is flexible with change of resources within the system (thus allowing for changes of supply base, and making it easy to deal with uncertainties involved in cost and lead time due to institutional issues). This is in contrast with traditional methods in this area which seek to optimise the supply chain configurations decisions directly.

IMPLEMENTATION

The flow chart in Figure 6 illustrates the operation of the implementation of the proposed method, where the processing of one chromosome is described. When a customer places an order for a product, the product agent retrieves the product's bill of materials (BOM). The retrieved information contains required quantities of parts/subassemblies, as well as the assembly/production operations involved in producing the product. The required parts/operations are then passed on to the process agent who makes up a sequential wish-list of tasks. The wish-list is basically, a sequence of parts/operations required to satisfy that order from procurement to final delivery. The process agent also generates a population of chromosomes corresponding to the product order. Each chromosome is then used to coordinate the bidding process, where the tasks on the wish list, along with their corresponding virtual prices, are announced one after another according to the sequence, for resource agents to bid. The announcement for each task is made via the facilitator agent in the form of an invitation-to-bid message. When resource agents receive an invitation to bid, the message would carry the following information; part/operation description and the corresponding virtual price. From their individual KBs, optional resource agents confirm their capabilities to carry out the task in question. Each resource agent has a minimum virtual profit from the chromosome (which is communicated to it by the process agent before announcement of any task). If a resource agent is capable of performing the task and the virtual profit from the task (i.e., the difference between virtual price for the task and the actual cost to perform the task) is greater than the minimum virtual profit, a **ready** message is sent to the process agent indicating the resource's interest in bidding for that task.

The resource agent then packages its bid and sends a **make-bid** message to the process agent via the facilitator agent. Bids sent to the process agent are of the format:

$$F(\mathrm{Bid}) = \{\mathrm{item.description}, \ \mathrm{resourceId}, \ \mathrm{quantity}, \ \mathrm{cost}, \ \mathrm{leadTime}\}$$

Bids for a task from optional resources are evaluated by the process agent. The bid with the shortest lead time is chosen as the successful one for this task with the current chromosome.

Once all tasks have been bid for, the successful bids for the tasks are used by the process agent to formulate a resource combination. The total cost and lead time (which is the summations of costs and lead times of successful bids for individual tasks respectively) corresponding to the combination is then recorded as the performance of the current chromosome. If the lead time does not meet the customer due date, the current chromosome is discarded. The process agent will then start to process the next chromosome as required by the GA algorithm. Once the GA process is completed (after a number of generations), the final best combination of resources, along with the corresponding cost and lead time for the product, are reported to the product agent.

TEST AND RESULTS

Test is carried out based on the laptop manufacturing example drawn from Huang et al., (2005). The products' structures and the corresponding supply chain have been discussed in Section 3.

Table 1 shows the parameters (cost and lead time) of each optional resource for each part or operation required by the products. The three orders considered for the products are shown in Table 2. This is different from the daily demand model used by Huang et el., 2005. Table 3 shows the best configuration for each of the three orders obtained with the proposed method, where resource options selected for each part/operation, and the corresponding lead-times and cost-added to overall product cost are included. The resulting total supply chain cost and lead-times for the three orders are given in Table 4. For each case, a population of 200 chromosomes were used and the optimum result achieved after 30 generations. The expected product due date for the orders was set to 80days at the beginning of computation, hence, the optimisation algorithm searches for the minimum total cost attainable provided the total lead-time does not exceed 80days.

[Insert Table 1 here]

[Insert Table 2 here]

Although for the purpose of configuring the supply chain to deal with orders over a period of time would ideally require a large number of orders to be forecast and processed, the processing of the three orders in the current test appears to show a common configuration for the type of demands represented. The test shows that most of the selected resources for the three orders are similar except for node 10 where different assembly plants are chosen for the two product types. This does appear to indicate that the manufacturer can fix most parts of its supply chain for the ranges of products.

[Insert Table 3 here]

[Insert Table 4 here]

CONCLUSIONS

Manufacturing supply chains usually consist of a number of autonomous or semi-autonomous business entities that are collectively responsible for performing a variety of tasks associated with satisfying product orders from customers. There may be several resource options available to carry out each task required for an order, and often a range of different products may be involved in the order. It is necessary for a manufacturing organisation to optimise the configuration of its supply chains such that product orders are duly satisfied without compromising due-dates while total costs are kept to minimum.

In this paper, we introduced the challenge of optimising supply chain configurations and presented an agent-based optimisation approach that generates alternative supply chain configurations in response to demand changes across a product mix. Contrary to the formation of short-term virtual alliances for each product order, the approach aims to fix a fairly stable supply chain for a manufacturing organisation such that orders across a mix of products can be satisfied. The proposed model represents the supply chain as a multi-agent system with agents representing resources such as suppliers, assembly plants and transportation options. We demonstrated how resource combinations can be achieved through coordinated agents' interactions and iterative bidding controlled by a genetic algorithm.

As a form of validation, we apply the proposed method to a supply chain configuration problem involving two laptop computer variants. Decisions on which optional resource should perform each part/operation required to satisfy the order is enabled by the agent-based optimisation approach. Computational results showed that resource choices can be optimised with the method and common configurations can be obtained across multiple orders. Future work will investigate how to cluster the resulting configurations for a number of orders to identify a best configuration that can be commonly used by the orders over a given period. Work is also on-going to investigate how to incorporate uncertainties in lead time and cost within the methods.

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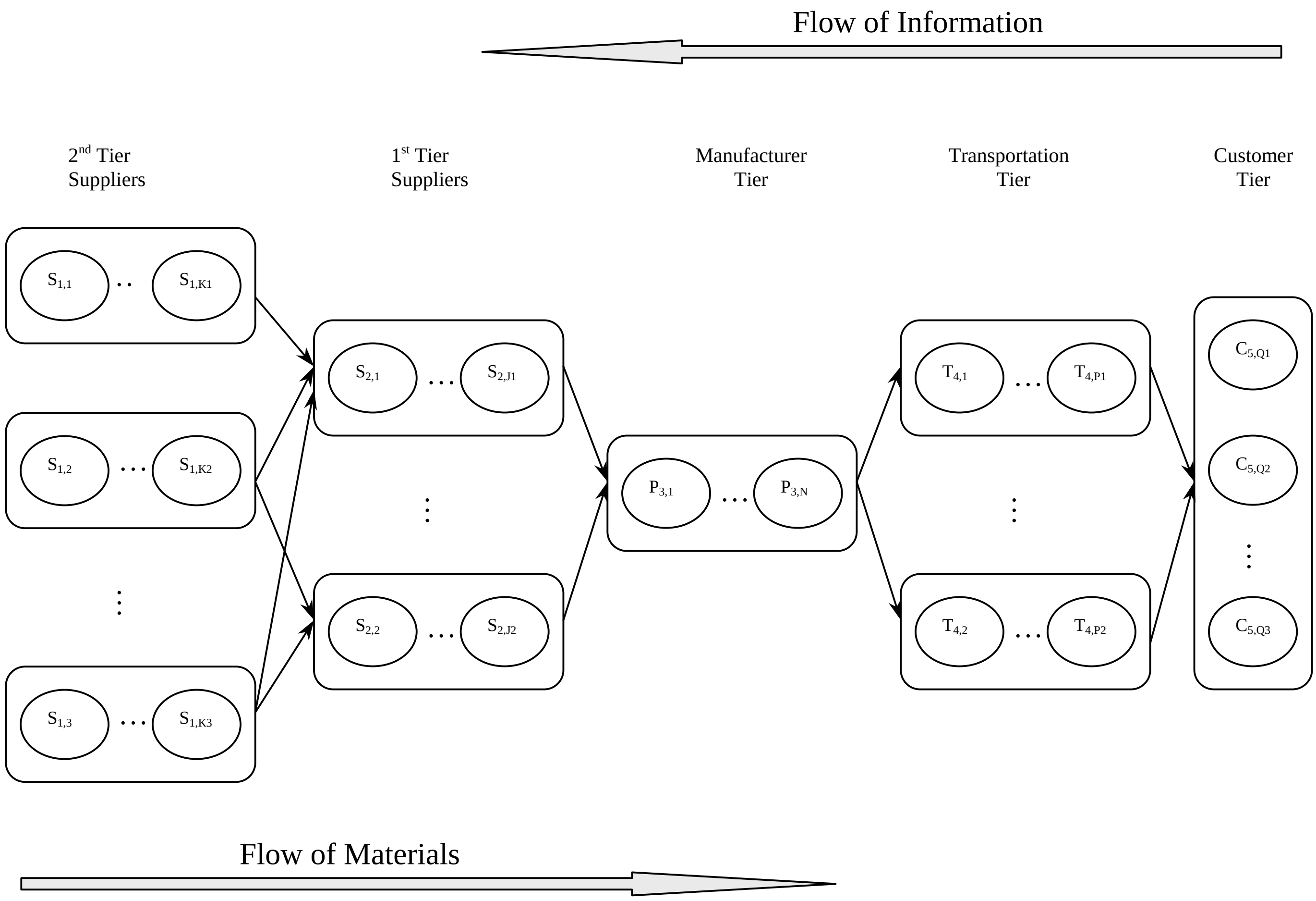

Figure 1 Generic Supply Chain with Five Tiers

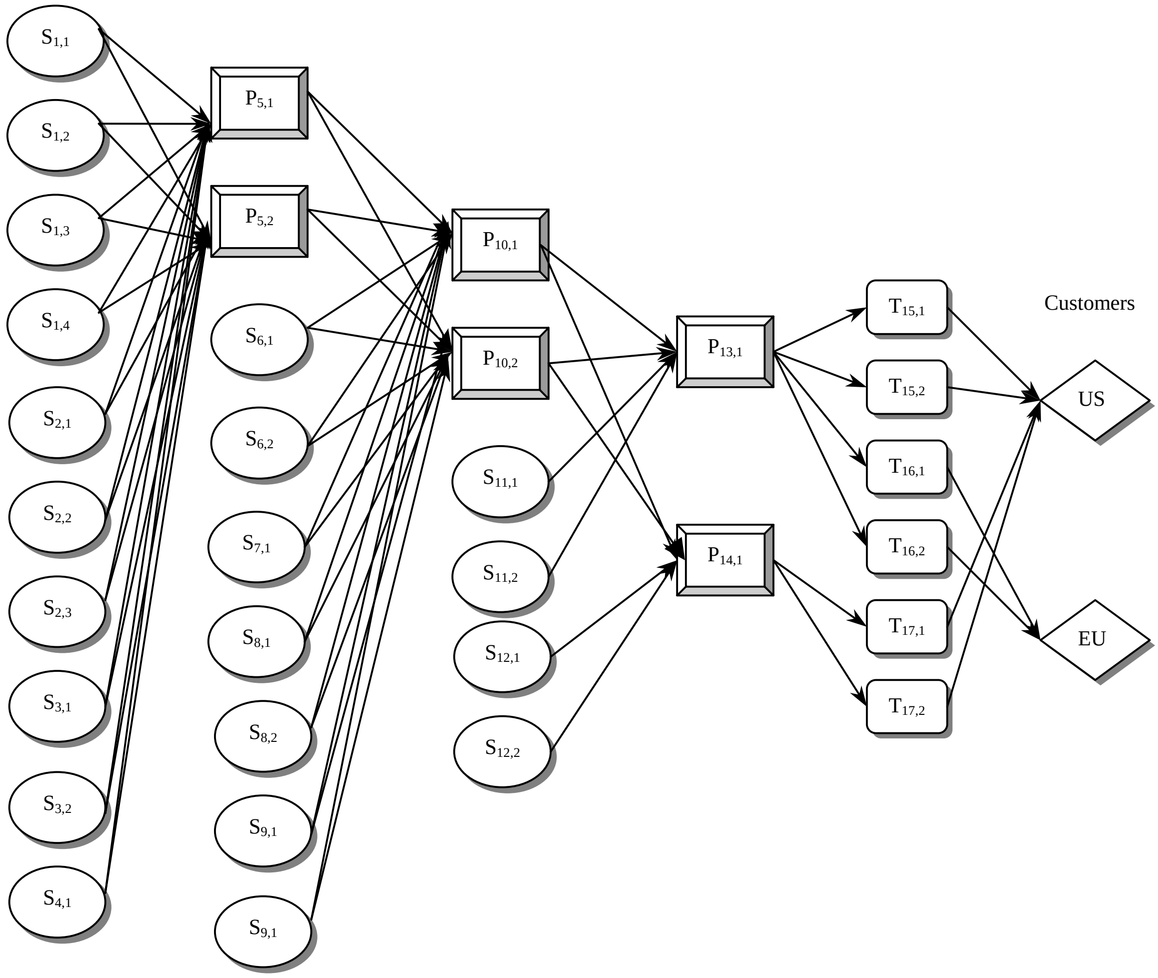

Figure 2 Supply Chain of Laptop Variants Showing Resource Options

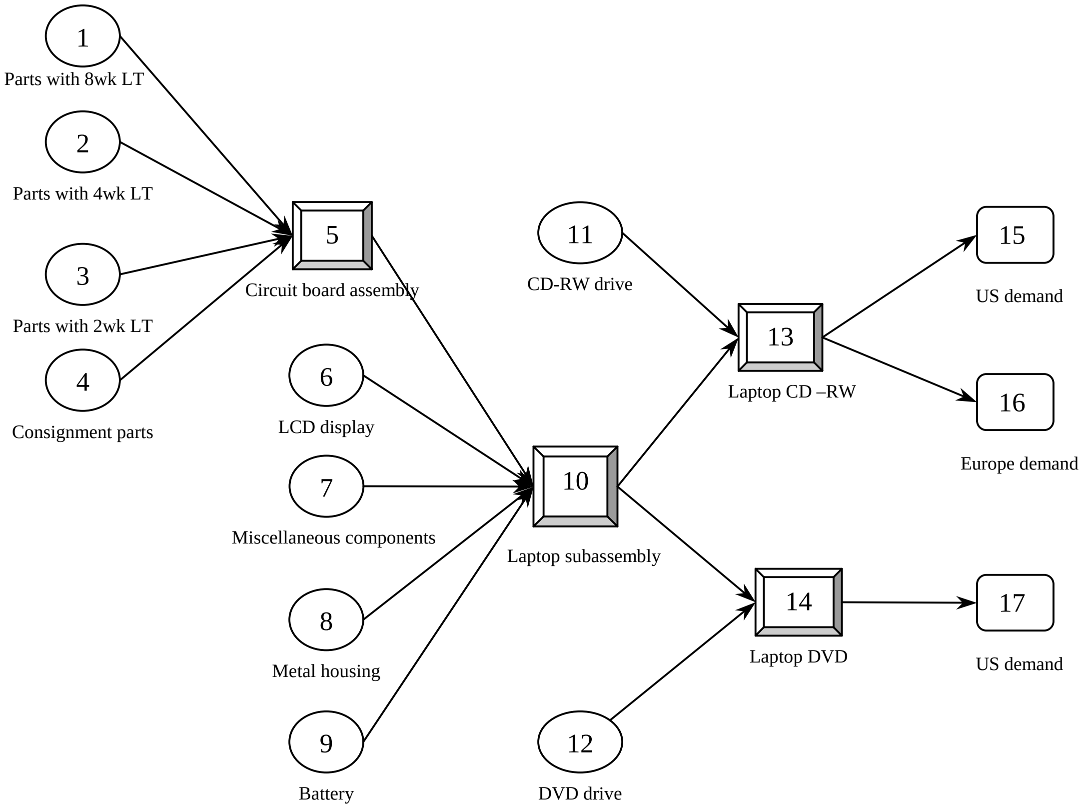

Figure 3 Required Parts / Operations for Satisfying Laptop Orders

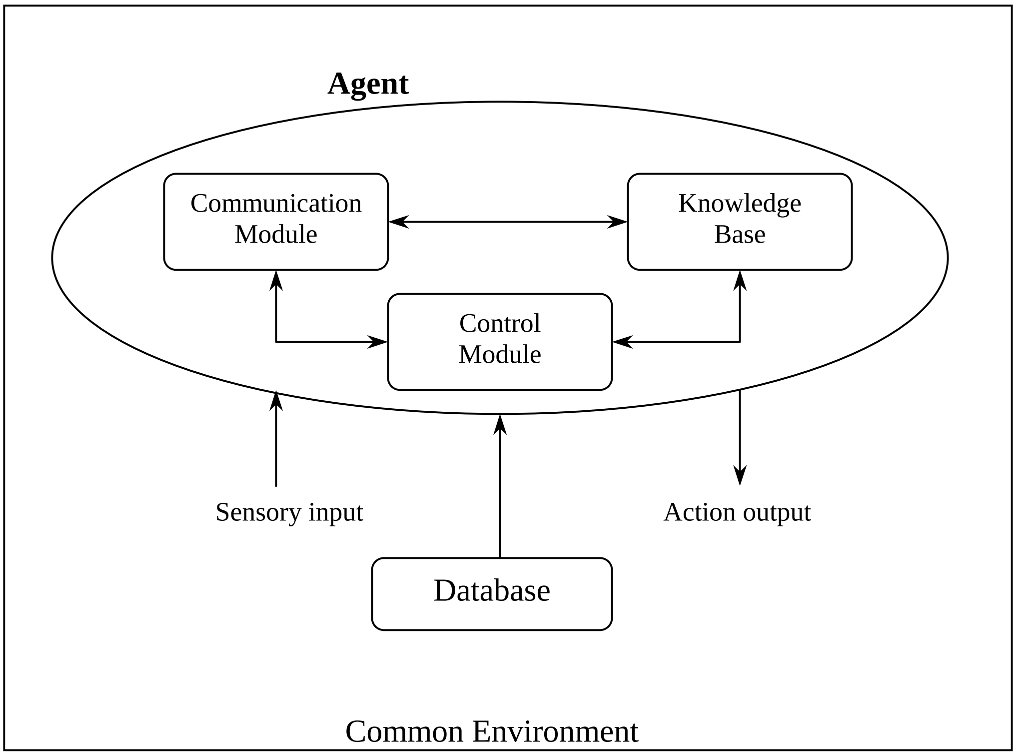

Figure 4 Architecture of an Individual Agent

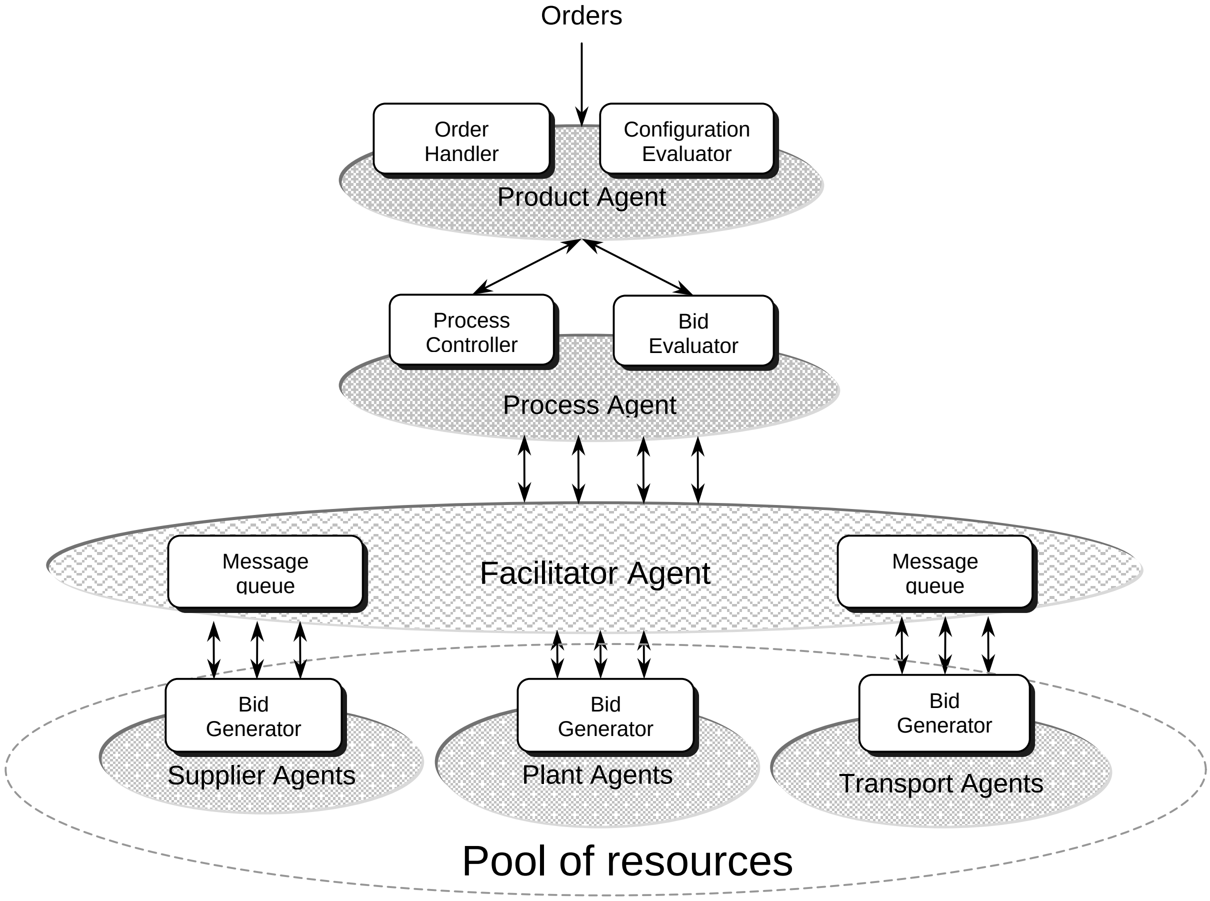

Figure 5 Multi-Agent Architecture

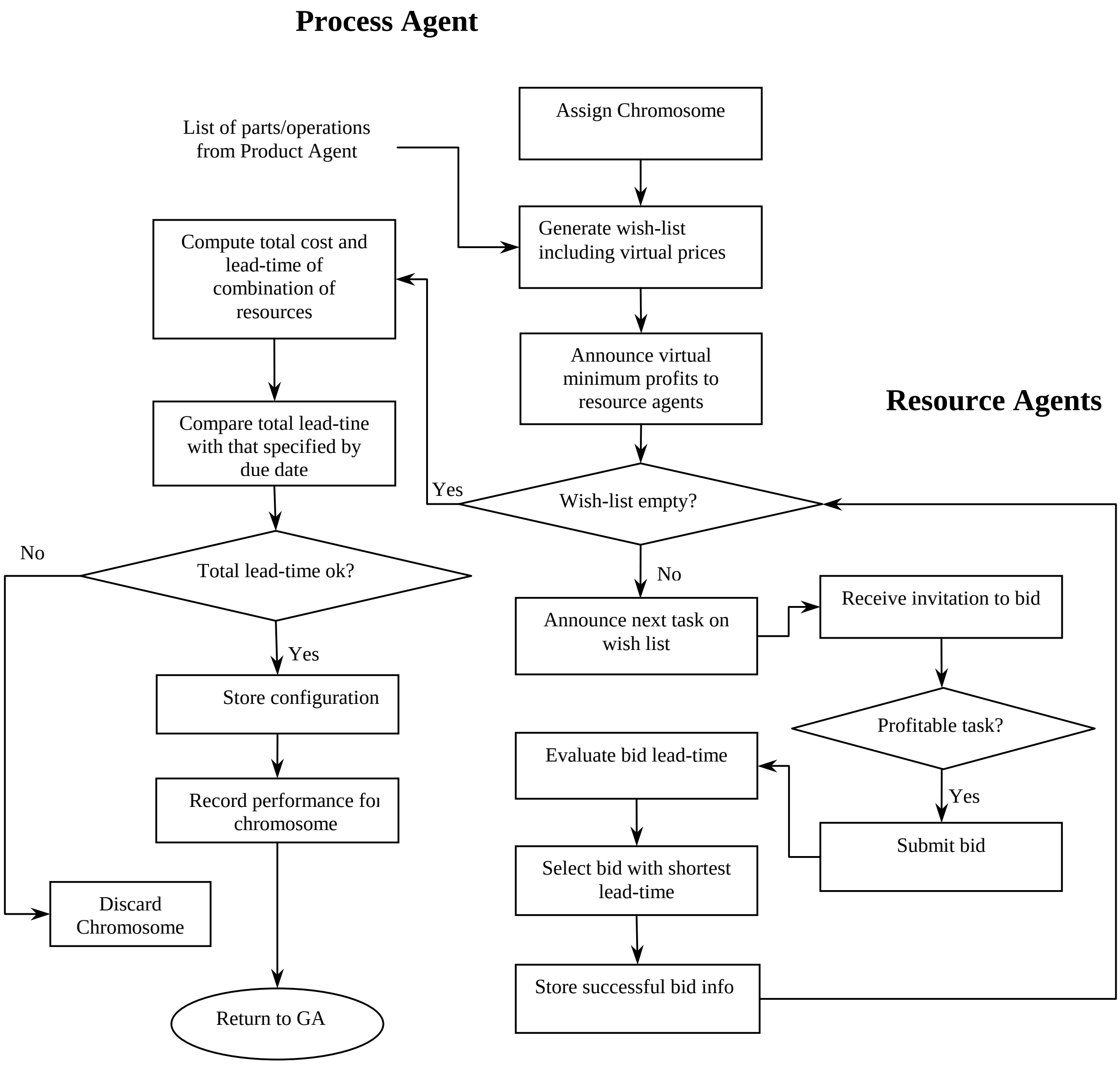

Figure 6 Flow Chart Showing the Processing of One Chromosome in an Iteration

Stage	Event Node	Components/Process Description	Option	Lead-Time	Cost ($)
1	1	Parts w/8 week LT	1	40	130.00
			2	20	133.25
			3	10	134.91
			4	0	136.59
	2	Parts w/4 week LT	1	20	200.00
			2	10	202.50
			3	0	205.30
	3	Parts w/2 week LT	1	10	155.00
			2	0	156.93
	4	Parts on Consignment	1	0	200.00
2	5	Circuit Board Assembly	1	20	120.00
			2	5	150.00
	6	LCD Display	1	60	300.00
			2	5	350.00
	7	Miscellaneous Components	1	30	200.00
	8	Metal Housing	1	70	225.00
			2	30	240.00
	9	Battery	1	60	40.00
			2	20	45.00
3	10	Laptop Assembly	1	5	120.00
			2	2	132.00
	11	CD-RW Drive	1	40	30.00
			2	5	35.00
	12	DVD Drive	1	40	15.00
			2	5	16.50
4	13	CD-RW Assembly	1	1	30.00
	14	DVD Assembly	1	1	30.00
5	15	US Demand - CD-RW Assembly	1	5	12.00
			2	1	20.00
	16	Europe Demand - CD-RW Assembly	1	15	15.00
			2	2	30.00
	17	US Demand - DVD Assembly	1	5	12.00
			2	1	20.00

Table 1 Resource Options for Laptop Computers (Source: Huang et al. 2005)

	Laptop-CD	**Laptop-DVD**
US Orders	200	125
European Orders	75	-

Table 2 Daily Orders for Laptop Products

Stage	Event Node	Components/Process Description	Resource Options		Lead-Time	Cost ($)
			CD-RW	DVD	Days	
1	1	Parts w/8 week LT	4	4	0	137.00
	2	Parts w/4 week LT	3	3	0	205.30
	3	Parts w/2 week LT	2	2	0	157.00
	4	Parts on Consignment	1	1	0	200.00
2	5	Circuit Board Assembly	1	1	20	120.00
	6	LCD Display	1	1	60	300.00
	7	Miscellaneous Components	1	1	30	200.00
	8	Metal Housing	2	2	30	240.00
	9	Battery	1	1	60	40.00
3	10	Laptop Assembly	2	1	2	132.00
	11	CD-RW Drive	1		40	30.00
	12	DVD Drive		1	40	15.00
4	13	CD-RW Assembly	1		1	30.00
	14	DVD Assembly		1	1	30.00
5	15	US Demand - CD-RW Assembly	1		5	12.00
	16	Europe Demand - CD-RW Assembly	1		15	15.00
	17	US Demand - DVD Assembly		1	5	12.00

Table 3 Resource Options Selected Using Agent-Based Optimisation Algorithm

Demand Markets	Laptop CD-RW		Laptop DVD
	US Market	Europe Market	US Market
Unit Product Cost	1791	1806	1776
Lead-time	71days	78days	71days

Table 4 Summary of Demand and Product Variants

OPTIMAL LOCATION AND VALUE OF TIMELY SORTING OF USED ITEMS IN A REMANUFACTURING SUPPLY CHAIN WITH MULTIPLE COLLECTION SITES

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ABSTRACT

We study a supply chain consisting of a central remanufacturing facility and a number of collection sites (CS). The central facility procures returned items from the CS for remanufacturing and sale. We examine whether it is advisable to establish a sorting procedure that identifies those units that are suitable for remanufacturing before disassembly. Sorting is subject to classification errors and may be performed either centrally or locally at the CS. Assuming stochastic demand, infinite horizon and deterministic yield at the CS we obtain the optimal parameters of the replenishment policy under each one of the three possible system configurations: no sorting, central sorting, local sorting. It is then easy to determine the value of sorting and the preferred CS for the procurement of returned items.

Keywords: reverse logistics, multi-period model, classification errors, multiple suppliers

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INTRODUCTION[#]

Among the distinguishing features of reverse supply chain management is the uncertainty about the quality of the returned used units, which determines their suitability for remanufacturing. There are two aspects of that uncertainty. First, the actual number of remanufacturable units contained in a lot of returned items is unknown. Second, even if that number can be estimated with adequate accuracy, there still exists the need to identify the specific remanufacturable units among the returns. It is obvious that if the information regarding quality of returns is improved, the efficiency of the entire reverse supply chain will certainly increase.

The issue of timely information about the quality of returns in reverse supply chains has been addressed in a number of recent papers. Most of these contributions deal with single-period models. In particular, Ferrer (2003) and Ketzenberg et al. (2004) study the difference in the operating costs of a remanufacturing facility when different degrees of information exist regarding the stochastic yield of returns. Guide et al. (2005) evaluate the potential savings from the use of error-free sorting at an early stage of a supply chain with deterministic yield of returns. The value of advanced yield information subject to grading errors is studied via simulation in Souza et al. (2002). Analytical expressions for the value of sorting at the remanufacturing facility in a single-period context are derived in Zikopoulos and Tagaras (2006b).

The motivation for analyzing single-period models is that there are many technologically innovative products such as PC, printers and cellular phones characterized by very short lifecycles. Nevertheless, single-period models are not

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appropriate for products with longer lifecycles, such as power tools (Debo et al., 2004), tires (Debo et al., 2005), bearings, etc. In the reverse supply chain literature there are many papers that study procurement and production decisions in a multi-period or infinite-horizon context; see Part III of Dekker et al. (2004). However, the main interest lies typically in the optimization of system operation from an inventory management point of view, without exploring in detail the consequences of poor quality of returns.

The objective of this paper is to study the value of early information about the remanufacturability of returns through testing and sorting before disassembly and remanufacturing. The context is a two-level reverse supply chain with one remanufacturing facility and N collection sites, which supply the remanufacturing facility with used products. The remanufacturing facility has the option to establish a sorting / testing procedure prior to the initialization of the disassembly and remanufacturing operation in order to identify the remanufacturable units before the typically expensive dismantling process. This sorting operation may take place at the remanufacturing facility or at the collection sites. In any case, the sorting procedure has limited accuracy. We derive analytical expressions for the optimization of the replenishment policy and conditions that determine when and where sorting is worthwhile from an economic point of view.

A publication with a similar orientation in a multi-period context is that of Ferrer and Ketzenberg (2004), who assume that the product consists of a number of parts which can be obtained either from a new parts manufacturer or by remanufacturing used ones. They study 4 models that differ in the timing of yield information compared to the new products procurement leadtime. Our work differs in that we examine a more complex supply chain and we allow for classification errors during the sorting procedure, while Ferrer and Ketzenberg (2004) study a more complex product structure. The present paper is also related to part of the work in Zikopoulos and Tagaras (2006b), where the infinite-horizon problem is examined briefly for the case of a reverse supply chain with a single CS and stochastic yield.

The next section describes the problem under consideration in more detail, followed by a section in which the relevant mathematical models are developed and the optimal parameters of the replenishment policy are also derived. In the "Comparison of the alternative systems" section, we characterize and discuss the conditions that indicate when a sorting procedure is economically advisable, while in the subsequent section a numerical example is presented, which illustrates the most interesting analytical results of the preceding sections. Finally, the last section concludes the paper with a summary and some ideas for future research.

PROBLEM DEFINITION AND ASSUMPTIONS

The reverse supply chain under examination consists of a central remanufacturing facility (R) and multiple collection sites (CS), denoted CS_i, i=1,2..N, where customers return used products at the end of their life or use. We assume that there is a continuous demand for remanufactured products, which is expressed by a stationary probability distribution with average yearly rate D.

The remanufacturing facility R reviews its inventory continuously. When the number of remanufactured items at R falls at a critical level (reorder point) s, the remanufacturing facility orders returned products from one or more CS with the intention to remanufacture them and thus replenish its inventory of remanufactured products. We assume that ample quantities of returns are available at all CS. The quantity ordered from CS_i is denoted by s_i and the total procurement quantity is $\sum_{i=1}^{N} s_i$. Each lot of s_i units consists of returned items of various quality states; some or even most of them may not be suitable for remanufacturing. Specifically, at each CS_i only a proportion q_i of the total quantity collected is in a condition such that it can be remanufactured successfully. We assume that the estimates of the fractions remanufacturable q_i (yield) are accurate enough to treat all q_i as known and constant. The cost of procuring a single unit from CS_i equals c_i. This cost may include the cost of purchase (acquisition) and/or handling and transportation.

The used items arriving at R can be disassembled at a cost of c_{da} per unit, in order to identify those units that are suitable for remanufacturing. Disassembly reveals with certainty the condition of each unit. Items that are not remanufacturable are disposed of at a cost of c_d per unit; the remainder of the lot is remanufactured at a cost of c_r per unit. All remanufactured units enter the serviceable inventory and incur a holding cost denoted by c_h per unit per year. Remanufactured units are sold at a price v per unit. In case of stockouts demand is not lost but is completely backlogged. The shortage cost is c_b per unit.

It is often technically feasible to establish some sorting / testing operation that may reveal with some accuracy which units are indeed remanufacturable, without going through the typically expensive disassembly process. The testing may take place at the CS, before the returned units are transported to R, or at R, just before disassembly. This sorting procedure is generally subject to errors of both types. Specifically, there is a proportion α of remanufacturable units that are incorrectly classified as non-remanufacturables (type I error) and a proportion β of non-remanufacturables that are incorrectly classified as remanufacturables (type II error). It is reasonable to assume that $\alpha+\beta < 1$. The sorting cost per unit is c_s when sorting is performed at R, while it is $c_s+\delta_s$ when sorting is carried out at the CS. All units classified as remanufacturable proceed to the next stage but their true condition is revealed with certainty only after disassembly at R. Thus, all units that undergo the actual remanufacturing operation are indeed remanufacturable, while all the non-remanufacturable units are disposed of after sorting or disassembly.

Regardless of whether and where sorting takes place, the central facility R faces a fixed cost, C, in every replenishment cycle, associated with the setup of all necessary operations for placing, receiving and processing an order. Moreover, we assume that the time period between the placement of an order and the time that remanufacturable units have been remanufactured and are available to satisfy demand is constant and unaffected by the existence of a sorting procedure and the size of the order. The distribution of demand for remanufactured items during that time interval (lead time) is assumed to be known with density and distribution functions f(.) and F(.), respectively and expected value equal to D_L. The notation used throughout the paper is summarized in Table 1.

MODEL FORMULATION

The formulation of the expected annual profit function is presented separately for the three alternative systems under consideration, namely:

- system without sorting (ns);
- system with sorting at R (sR);
- system with sorting at the CS (sC).

R:	Remanufacturing facility
CS:	Collection site
ns	system without sorting
sR	system with sorting at R
sC	system with sorting at CS
i:	index of CS (i=1,2,…,N)
s_i:	quantity ordered from CS_i
C:	Fixed cost per order
c_s:	sorting cost per unit at R
δ_s:	additional sorting cost per unit when sorting takes place at the CS
c_{da}:	disassembly cost per unit
c_i:	acquisition/transportation cost from CS_i per unit
c_d:	disposal cost at R per non-remanufactured unit
c_r:	remanufacturing cost per unit
v:	sales revenue per unit
c_b:	shortage cost per unit
c_h:	annual holding cost per unit
s:	reorder point
α:	proportion of remanufacturables misclassified as non-remanufacturables
β:	proportion of non-remanufacturables misclassified as remanufacturables
q_i:	fraction of remanufacturables at CS_i
x:	demand for remanufactured units during lead time (random variable)
f(x):	probability density function of x
F(x):	distribution function of x
D_L	mean value of random variable x
D	average annual demand for remanufactured units

Table 1. Notation

In all cases we assume that average backorders are much lower than average stock on hand. Therefore, since out of a total order quantity $\sum_{i=1}^{N} s_i$ the expected number of items that will be remanufactured is $(1-\alpha)\sum_{i=1}^{N} s_i q_i$ (α=0 for the ns system), the average inventory of available remanufactured items is approximated by

$$\left((1-a)\sum_{i=1}^{N} s_i q_i \Big/ 2\right) + s - D_L \,.$$

On the other hand, the expected number of units short per replenishment cycle is:

$$n(s) = \int_{s}^{\infty} (x-s) f(x) dx \,,$$

while the average number of replenishment cycles per year is

$$\frac{D}{(1-a)\sum_{i=1}^{N} s_i q_i} \,.$$

The replenishment policy is fully defined by the values of the reorder point s and the order quantities (procurement lot sizes) s_i, i=1,2,…,N, which together constitute the set of decision variables.

Disassembly without prior sorting (ns)

The expected annual profit can be written as the following function of the decision variables:

$E[TP_{ns}(s_1,\ldots,s_N,\, s)]$

$$= \left[v\sum_{i=1}^{N} s_i q_i - c_b n(s) - c_r \sum_{i=1}^{N} s_i q_i - c_d \sum_{i=1}^{N} s_i \left(1-q_i\right) - c_{da} \sum_{i=1}^{N} s_i - \sum_{i=1}^{N} c_i s_i - C \right] \frac{D}{\sum_{i=1}^{N} s_i q_i}$$

$$-c_h \left[\left(\sum_{i=1}^{N} s_i q_i \Big/ 2 \right) + s - D_L \right]. \quad \mathbf{(1)}$$

The terms of (1) correspond to sales revenues, backorder cost, remanufacturing cost, cost of disposal of the non-remanufacturable units, disassembly cost, procurement (transportation/acquisition) cost, fixed cost per order and inventory holding cost. After some algebraic manipulation (1) becomes

$E[TP_{ns}(s_1,\ldots,s_N, s)]$

$$= (v - c_r + c_d)D - \left[c_b n(s) + (c_d + c_{da})\sum_{i=1}^{N} s_i + \sum_{i=1}^{N} c_i s_i + C\right]\frac{D}{\sum_{i=1}^{N} s_i q_i}$$

$$-c_h\left[\left(\sum_{i=1}^{N} s_i q_i \Big/ 2\right) + s - D_L\right]. \quad \textbf{(2)}$$

Since the available quantities of returns are practically unlimited at all CS it is reasonable to consider procurement from a single CS, the one with the most appealing cost and quality characteristics. To be more specific, the attractiveness of each particular CS depends on the relative values of its fraction remanufacturable and procurement cost and on the disposal and disassembly costs. Proposition 1 shows that single sourcing is indeed optimal and identifies the particular CS that should be used as the sole supplier of R.

Proposition 1

The optimal procurement policy in ns is single sourcing from the CS with the lowest ratio

$$\frac{c_i + c_d + c_{da}}{q_i}, \quad i=1,2,\ldots,N. \qquad \textbf{(3)}$$

Proof: See Appendix. ■

Since $1/q_i$ is the expected total number of returned items at CS_i corresponding to a single remanufacturable unit, the ratio $(c_i + c_d + c_{da})/q_i$ can be viewed as a measure of the cost of procurement from CS_i, increased by the expected waste due to transportation, disassembly and disposal of non-remanufacturable items. In other words, the interpretation of Proposition 1 is that the choice of the supplying CS must be based on the simultaneous consideration of the direct acquisition cost and the indirect cost of poor quality, which in this case is translated into waste associated with the handling of non-remanufacturables. Note that this interpretation is fully consistent with analogous findings in the broader context of supplier evaluation; see, for example, Tagaras and Lee (1996).

The optimal values of s_i and s are obtained by differentiating (2) with respect to s_i and s and setting both first-order derivatives equal to zero, which results in the following system of equations:

$$s_i q_i = \sqrt{\frac{2D[C + c_b n(s)]}{c_h}} \qquad \textbf{(4)}$$

and

$$1 - F(s) = \frac{c_h s_i q_i}{c_b D} = \sqrt{\frac{2c_h[C + c_b n(s)]}{c_b^2 D}}\,. \qquad \textbf{(5)}$$

It is readily observed that the optimal reorder point, s, and the number of remanufacturables available at R, $s_i q_i$, are unaffected by the choice of the supplying CS_i. A practically useful implication is that if for some reason the preferable CS_i is unavailable, the remanufacturing firm should proceed with the second best CS_j with the same s and $s_j = s_i q_i / q_j$.

The fact that the optimal number of remanufacturables procured is independent of the CS used is useful in further clarifying and reinforcing the intuition behind Proposition 1. Specifically, note that since the optimal number of remanufacturables that should be available at R is constant, the difference in profits between two configurations that use two different CS, e.g. CS_i and CS_j, comes exclusively from the difference in total procurement cost, c_i/q_i - c_j/q_j (per remanufacturable unit) and the difference in the processing cost of the expected number of non-remanufacturables per remanufacturable unit, which is

$$(c_d+c_{da})\ [(1-q_i)/q_i-(1-q_j)/q_j] = (c_d+c_{da})\ (1/q_i-1/q_j).$$

Consequently, the difference in profit is $(c_i + c_d + c_{da})/q_i$ - $(c_j + c_d + c_{da})/q_j$ multiplied by a constant, which means that the most preferable CS is determined by the value of the ratio $(c_i + c_d + c_{da})/q_i$.

Sorting at R before disassembly (sR)

Assuming that the total quantity procured undergoes the sorting procedure, all units classified as remanufacturables are disassembled and all disassembled remanufacturables are remanufactured, the expected annual profit can be written as the following function of procurement quantities s_i, i=1,2,…,N and reorder point s:

$E[TP_{sR}(s_1,\dots,s_N,s)]$

$$= \Big\{ v(1-\alpha)\sum_{i=1}^{N} s_i q_i - c_b n(s) - c_r(1-\alpha)\sum_{i=1}^{N} s_i q_i - c_d \sum_{i=1}^{N} s_i \left[\alpha q_i + (1-q_i)\right]$$

$$- c_{da}\sum_{i=1}^{N}\left[(1-\alpha)q_i + \beta(1-q_i)\right]s_i - \sum_{i=1}^{N} c_i s_i - c_s \sum_{i=1}^{N} s_i - C \Big\} \frac{D}{(1-\alpha)\sum_{i=1}^{N} s_i q_i}$$

$$- c_h\left[\left((1-\alpha)\sum_{i=1}^{N} s_i q_i \Big/ 2\right) + s - D_L\right]. \qquad \textbf{(6)}$$

The terms in (6), in the order they appear, correspond to sales revenues, backorder cost, remanufacturing cost, cost of disposing of the non-remanufacturable units, disassembly cost, transportation/acquisition cost, sorting cost, fixed cost per order and inventory holding cost. After some algebraic manipulation (6) becomes

$$E[TP_{sR}(s_1,\ldots,s_N,s)] = (v-c_r)D-\Big\{c_b n(s)+c_d\sum_{i=1}^{N}s_i\left[\alpha q_i+(1-q_i)\right]$$

$$+c_{da}\sum_{i=1}^{N}[(1-\alpha)q_i+\beta(1-q_i)]s_i+\sum_{i=1}^{N}c_i s_i+c_s\sum_{i=1}^{N}s_i+C\Big\}\frac{D}{(1-\alpha)\sum_{i=1}^{N}s_i q_i}$$

$$-c_h\left[\left((1-\alpha)\sum_{i=1}^{N}s_i q_i\Big/2\right)+s-D_L\right]. \quad \textbf{(7)}$$

Similar to the system without sorting, single sourcing is still optimal as explained by Proposition 2 below.

Proposition 2

The optimal procurement policy in sR is single sourcing from the CS with the lowest ratio

$$\frac{c_i+c_s+c_d+c_{da}\beta}{q_i},\quad i=1,2,\ldots,N. \quad \textbf{(8)}$$

Proof: Omitted, because it is almost identical to that of Proposition 1. ■

The intuitive explanation of the meaning of $(c_i+c_s+c_d+c_{da}\beta)/q_i$ is analogous to the respective ratio appearing in Proposition 1 for the ns system. The difference in the sR system is that non-remanufacturable units incur an additional cost for sorting, c_s per unit, but the disassembly cost is incurred only by a proportion β of the non-remanufacturables, i.e. those that were incorrectly classified as remanufacturable. Note that the choice of CS does not depend on the type I error parameter α because that error affects only the remanufacturable items $s_i q_i$ that have been delivered to R, which are again independent of the supplying CS_i as is shown immediately below.

The first-order conditions for the optimization of (7) under the optimal single-sourcing policy are

$$s_i q_i \left(1 - \alpha\right) = \sqrt{\frac{2D[C + c_b n(s)]}{c_h}} \qquad \textbf{(9)}$$

and

$$1 - F(s) = \frac{c_h s_i q_i \left(1 - \alpha\right)}{c_b D} = \sqrt{\frac{2c_h [C + c_b n(s)]}{c_b^2 D}}\,. \qquad \textbf{(10)}$$

It is interesting that the critical ratios appearing in Propositions 1 and 2 are not necessarily minimal at the same CS. In other words, the establishment of a sorting procedure at R may change the preferred CS. Which of the two configurations is most effective is examined in detail in Section 4. However, comparing (9) and (10) against (4) and (5) respectively, we conclude that the optimal reorder point and total number of delivered items that will be remanufactured at R are unaffected by the existence of sorting and by the characteristics of the supplying CS.

Sorting at CS before transportation (sC)

When sorting is carried out at the CS, we assume that the same sorting method is used and therefore the accuracy is the same with that of centralized sorting. However, it is conceivable that sorting at the remanufacturing facility may be performed more efficiently and consequently we allow the sorting cost at the CS to be higher than the respective cost at R; sorting at the CS costs $c_s+\delta_s$ per unit, where $\delta_s \geq 0$. The assumptions made for the sR system in the previous section, about disassembly of the total quantity classified as remanufacturable and remanufacturing of all available remanufacturables after disassembly, apply in this case as well.

The expected annual profit function is similar to that of the sR system but with two differences, in addition to the sorting cost: (a) only units classified as remanufacturable are transported to R and incur the acquisition/transportation cost and (b) only the misclassified non-remanufacturables must be disposed of at R. The expected annual profit is written as follows:

$E[TP_{sC}(s_1,\ldots,s_N,s)]$

$$=\left\{v(1-\alpha)\sum_{i=1}^{N}s_iq_i-c_bn(s)-c_r(1-\alpha)\sum_{i=1}^{N}s_iq_i-c_d\sum_{i=1}^{N}s_i\beta(1-q_i)\right.$$

$$\left.-c_{da}\sum_{i=1}^{N}[(1-\alpha)q_i+\beta(1-q_i)]s_i-\sum_{i=1}^{N}c_i[(1-\alpha)q_i+\beta(1-q_i)]s_i-(c_s+\delta_s)\sum_{i=1}^{N}s_i-C\right\}\frac{D}{(1-\alpha)\sum_{i=1}^{N}s_iq_i}$$

$$-c_h\left[\left((1-\alpha)\sum_{i=1}^{N}s_iq_i\Big/2\right)+s-D_L\right], \quad \textbf{(11)}$$

which, after some algebraic manipulation, becomes

$$E[TP_{sC}(s_1,\ldots,s_N,s)] = (v-c_r)D-\left\{c_bn(s)+c_d\sum_{i=1}^{N}s_i\beta(1-q_i)+c_{da}\sum_{i=1}^{N}[(1-\alpha)q_i+\beta(1-q_i)]s_i\right.$$

$$\left.+\sum_{i=1}^{N}c_i[(1-\alpha)q_i+\beta(1-q_i)]s_i+(c_s+\delta_s)\sum_{i=1}^{N}s_i+C\right\}\frac{D}{(1-\alpha)\sum_{i=1}^{N}s_iq_i}$$

$$-c_h\left[\left((1-\alpha)\sum_{i=1}^{N}s_iq_i\Big/2\right)+s-D_L\right]. \quad \textbf{(12)}$$

Proposition 3 shows that single sorting is still the optimal policy and derives the condition that identifies the most preferable CS.

Proposition 3

The optimal procurement policy in sC is single sourcing from the CS with the lowest ratio

$$\frac{c_i\left[(1-\alpha)q_i+(1-q_i)\beta\right]+(c_s+\delta_s)+(c_d+c_{da})\beta}{q_i}, \quad i=1,2,\ldots,N. \quad \textbf{(13)}$$

Proof: Omitted, because it is essentially the same as that of Proposition 1. ■

The critical ratio of Proposition 3 bears similarities with the respective ratios of Propositions 1 and 2 but the unit acquisition/transportation cost c_i in the numerator of (13) is multiplied by the term $\left[(1-\alpha)q_i+(1-q_i)\beta\right]$, which accounts for the reduction in the quantity transported due to local sorting at the CS.

Since the determination of the optimal replenishment parameters under single sourcing is not affected by disposal, transportation and sorting costs, the optimality conditions for (12) are identical to those of the sR system. Consequently, the optimal s and s_i are derived by (9) and (10). However, in the sC system the most preferable CS is defined by the minimization of (13), which is not equivalent to the minimization of (3) or (8). Therefore, there may be different CS preferred in each case. It is interesting, though, that the optimal reorder point and the quantity that must be eventually remanufactured at R remain unaffected.

COMPARISON OF THE ALTERNATIVE SYSTEMS

In the current section we compare the three alternative system configurations presented in the previous sections and we provide the conditions under which each of them is optimal. In what follows we denote by CS_i the most preferable CS for the ns system, while the most preferable collection sites for the systems sR and sC are denoted by CS_j and CS_k respectively. The optimal configuration is determined by examining the signs of

$$\Delta_{0R} = c_s q_i - c_{da} q_i\left(1-q_j\right)(1-\alpha-\beta)+\left[c_i q_j(1-\alpha)-c_j q_i\right]+c_d\left[q_j(1-\alpha)-q_i\right] \qquad \textbf{(14)}$$

$$\begin{aligned}\Delta_{0C} = {} & \left(c_s+\delta_s\right)q_i \\ & -\left(c_{da}+c_d\right)\left[q_k\left(1-q_i\right)(1-\alpha)-\left(1-q_k\right)q_i\beta\right]+\left(c_i-c_k q_i\right)q_k(1-\alpha)-c_k\left(1-q_k\right)q_i\beta \qquad \textbf{(15)}\end{aligned}$$

$$\begin{aligned}\Delta_{RC} = {} & \left(c_{da}\beta+c_s\right)\left(q_j-q_k\right)+\delta_s q_j-\left\{c_j q_k-c_k q_j\left[(1-\alpha-\beta)q_k+\beta\right]\right\} \\ & +c_d\left[(1-\alpha-\beta)q_k q_j-q_k+\beta q_j\right]. \qquad \textbf{(16)}\end{aligned}$$

The above expressions determine the signs of differences in optimal expected profit between systems ns and sR (Δ_{0R}), ns and sC (Δ_{0C}), and sR and sC (Δ_{RC}). For example, $\Delta_{0R} > 0$ if and only if the optimal expected profit of system ns is higher than the optimal expected profit of sR. Proposition 4 summarizes the conditions under which each configuration dominates the others.

Proposition 4

- Disassembly without prior sorting (ns) is optimal if $\Delta_{0R} \geq 0$ and $\Delta_{0C} \geq 0$.
- Sorting at R before disassembly (sR) is optimal if $\Delta_{0R} < 0$ and either (a) $\Delta_{0C} \geq 0$, or (b) $\Delta_{0C} < 0$ and $\Delta_{RC} \geq 0$.
- Sorting at CS before transportation (sC) is optimal if $\Delta_{0C} < 0$ and either (a) $\Delta_{0R} \geq 0$, or (b) $\Delta_{0R} < 0$ and $\Delta_{RC} < 0$.

Proof: It follows directly from the definition of Δ_{0R}, Δ_{0C}, and Δ_{RC}. ■

The rather complicated form of Δ_{0R}, Δ_{0C}, and Δ_{RC} can be attributed to the existence of two differentiating elements in each pair of systems compared: the CS used and the existence/location of sorting. Simpler forms can be obtained in the case where the same CS is optimal under all three configurations. In that case Δ_{0R}, Δ_{0C}, Δ_{RC} simplify to the following

$$\Delta_{0R} = c_s + \alpha(c_i + c_d) - c_{da}(1-q_i)(1-\alpha-\beta) \qquad \textbf{(17)}$$

$$\Delta_{0C} = c_s + \delta_s - (c_{da} + c_d + c_i)(1-q_i)(1-\alpha-\beta) \qquad \textbf{(18)}$$

$$\Delta_{RC} = \delta_s - (c_i + c_d)\left[(1-\beta)(1-q_i) - \alpha q_i\right]. \qquad \textbf{(19)}$$

The terms that appear in (14) - (16) but not in (17) - (19) are those related to different CS used by the three systems. The remaining terms in (17) - (19) account exclusively for differences resulting from the different system structure with respect to the sorting policy for returned items and thus they have interesting and clear intuitive interpretations. For example, the form of (17) implies that sorting at R (sR) is more profitable than no sorting (ns) if and only if the cost of sorting per unit, c_s, is lower than $c_{da}(1-q_i)(1-\beta)-\alpha[c_i+c_d+c_{da}(1-q_i)]$, namely the expected per unit savings from avoiding disassembly of those non-remanufacturables that have been correctly identified as such by the sorting operation, reduced by the cost of type I errors. Expressions (18) and (19) have similar interpretations.

An obvious case where there is a dominant CS under all three different configurations is when a certain CS has the lowest acquisition/transportation cost and the best quality. More generally, if $q_i < q_j$ and $c_i \geq c_j$ for some pair of CS_i, CS_j, then it is intuitively clear and easily proved using Propositions 1, 2 and 3 that CS_j dominates CS_i under all system configurations and consequently CS_i can be excluded from further consideration as a candidate supplier. However, higher quality of returns at a CS is usually associated with higher acquisition cost from that CS. Thus, after excluding any immediately dominated collection sites, there will normally remain a number of candidate CS, which are not immediately dominated by some other CS but exhibit a clear ordering in terms of quality and acquisition cost: if $q_i \geq q_j$ then $c_i \geq c_j$ for every pair CS_i, CS_j of these collection sites. In those cases, it is still possible to have a single dominant CS for all three alternative systems if certain conditions hold. For example, it is easy to prove the following:

- If for the system without sorting (ns) it is optimal to procure from the CS_i with the lowest acquisition cost c_i (and worst quality q_i) and

$$c_{da}(1-\beta) > c_s + \delta_s \,, \qquad \textbf{(20)}$$

  then CS_i dominates all available CS for all three systems examined (ns, sR, sC).

- If for the system with sorting at CS (sC) it is optimal to procure from the CS_i with the best quality q_i (and highest acquisition cost c_i) and

$$c_d(1-\beta) > \delta_s \qquad \textbf{(21)}$$

$$c_{da}(1-\beta) > c_s \qquad \textbf{(22)}$$

  then CS_i dominates all available CS for all three systems examined (ns, sR, sC).

Note that although conditions (20) and (21)-(22) are sufficient in their respective contexts, they are not necessary for the dominance of CS_i.

ILLUSTRATION AND DISCUSSION

Consider a reverse supply chain like the one described in section 2 with three collection sites CS_1, CS_2, CS_3 and practically unlimited available returns. The acquisition / transportation costs per unit and the fractions remanufacturable of the used items collected at the three CS are c_1 = 60, c_2 = 56, c_3 = 53 and q_1 = 0.60, q_2 = 0.58, q_3 = 0.55 respectively. Thus, CS_1 can be viewed as the most expensive but higher quality supplier, followed in turn by CS_2 and CS_3. The cost of disassembly at R is c_{da} = 200 per unit. To simplify computations the disposal cost is taken to be negligible: c_d = 0.

By Proposition 1 the preferred CS in the absence of sorting is CS_1; CS_2 is second best and CS_3 is the least attractive supplier. Suppose now that a sorting operation is feasible with type I and type II error proportions α = 0.20 and β = 0.02 respectively and per unit cost c_s = 10, if sorting takes place at R, or $c_s + \delta_s$ = 12, if sorting is done locally at the CS. Using Proposition 2 and the critical ratio $(c_i + c_s + c_d + c_{da}\beta)/q_i$ we observe that CS_2 becomes the preferred CS for sorting at R, followed by CS_3. Finally, Proposition 3 and the critical ratio

$\left\{c_i\left[(1-\alpha)q_i+(1-q_i)\beta\right]+(c_s+\delta_s)+(c_d+c_{da})\beta\right\}/q_i$ indicate that with sorting at the collection sites profits are maximized when CS_3 is the single supplier, while CS_2 is the second best choice. Thus, in this numerical example the optimal CS depends on the existence and location of sorting; as we move from no sorting (ns) to sorting at R (sR) and then to local sorting at CS (sC), we observe a change in preference from the most expensive highest quality CS to the least expensive lowest quality CS, since the latter benefits most from the possibility of earlier sorting and removal of non-remanufacturable items.

The optimal values of the reorder point and the order quantities for the three systems are computed from (4) and (5) and from (9) and (10). Specifically, using c_h = 10, c_b = 100, C = 300 and D = 6000 and assuming that the demand over the lead time (approximately one week) follows a normal distribution with mean D_L = 120 and standard deviation σ_L = 10, the (common) optimal reorder point is s = 143 and the optimal order quantity s_i satisfies (1-α) s_iq_i = 603 for the preferred CS_i of each system. Thus, the vectors (s_1, s_2, s_3) of optimal procurement quantities for the ns, sR and sC systems are (1005, 0, 0), (0, 1300, 0) and (0, 0, 1370), respectively. In all three systems the probability of no stockout in every replenishment cycle is 99%, while the expected number of annual replenishment cycles is 9,95. Note that all these results are independent of v and c_r, because although the values of these parameters are crucial for the profitability of the system they have no effect on the optimal procurement policy.

Substituting for the numerical values in (14), (15) and (16) with i=1, j=2, k=3 yields $\Delta_{0R} < 0$, $\Delta_{0C} < 0$ and $\Delta_{RC} < 0$. Hence, by Proposition 4 sorting at the single supplier of returned items CS_3 is the optimal system configuration. The optimal $E[TP_{ns}(s_1,s)]$, $E[TP_{sR}(s_2,s)]$, $E[TP_{sC}(s_3,s)]$ are computed using v = 400, c_r = 30 and the results are reported in Table 2, where the total expected annual profits are broken down into their components. Note that certain terms of the expected annual profit, namely the expected revenues, remanufacturing cost, inventory holding cost and backorder cost, are identical for all three systems. Also note that the sC system is characterized by higher sorting and disassembly costs than the sR system, but sC emerges as the optimal system configuration thanks to the great reduction in acquisition/transportation cost, which is the result of local sorting at the collection site. A final interesting observation from Table 2 is that without the sorting option the operation of the system would not be viable because of the high disassembly cost, which the sorting mechanism reduces substantially. Thus, in this particular example the benefits of timely sorting far outweigh its costs.

System	ns	sR	sC
revenues	2,400,000	2,400,000	2,400,000
sorting cost	-	129,310	163,636
acquisition cost	600,000	750,000	324,505
disassembly cost	2,000,000	1,221,724	1,224,545
remanufacturing cost	180,000	180,000	180,000
set-up cost	2,985	2,985	2,985
inventory holding cost	3,245	3,245	3,245
backorder cost	4	4	4
optimal total profit	- 386,234	112,732	501,080

Table 2. Annual expected revenues, costs and expected profits of the optimal policies for the three alternative system configurations

CONCLUSION AND FUTURE RESEARCH

We have examined the feasibility of establishing an early sorting operation in a reverse supply chain with multiple collection sites and a central remanufacturing facility in a random-demand, infinite-horizon context. We have formulated the expected annual profit functions for the cases without sorting, with central sorting at the remanufacturing facility, with local (decentralized) sorting at the collection sites and we have specified the optimal procurement decisions in every case. Furthermore, we have derived the conditions under which each one of the three alternative system structures is dominating the others.

The entire analysis is based on the assumption that the yields (fractions remanufacturable) at all collection sites are deterministic, which allows a proper ranking of the collection sites that takes into consideration their particular characteristics as well as the system structure (existence and location of sorting). Under this assumption it turns out that the optimal procurement policy is single sourcing from the most highly ranked collection site.

An immediate extension of practical interest is the case of fractions remanufacturable that cannot be accurately estimated. In this random-yield version of the problem the optimal policy may call for procurement from multiple collection sites even when the available returns are practically unlimited. The case of only two collection sites has been studied by Zikopoulos and Tagaras (2006a) in the single-period context. The generalization to multiple collection sites with stochastic yields in the infinite horizon appears to be much more complicated and constitutes an interesting area for future research.

Another interesting extension of the present work concerns the determination of the optimal system design and procurement policy when the quantities of available returned items at the collection sites are limited. In that case it may be necessary to use multiple suppliers (collection sites) when a replenishment must take place. A reasonable heuristic would be to rely on the relative ranking of the suppliers, according to Propositions 1, 2, 3, and procure as many items as possible from each supplier in turn until the required quantity is assembled. However, the exact optimal policy should take into account the collection rates at the various collection sites, which are not deterministic in general, and consequently the mathematical analysis is greatly complicated. Therefore, the case of limited returns availability is yet another fruitful research area of practical interest.

APPENDIX

Proof of Proposition 1

The proof is given in two steps. First, we prove that if only one CS may be used, it is optimal to use the one that minimizes (3). Then, we prove that single sourcing is the optimal policy.

Consider that the optimal pair of parameters when using only an arbitrary CS_j is (s_j, s). The expected annual profit is:

$$E[TP_{ns}(s_j, s)] = (v - c_r + c_d)D - \left[c_b n(s) + (c_d + c_{da})s_j + c_j s_j + C\right]\frac{D}{s_j q_j} - c_h\left(\frac{s_j q_j}{2} + s - D_L\right). \quad \textbf{(A1)}$$

Consider now a replenishment policy with the same reorder point, s, but procurement only from CS_i. Moreover, assume that the order quantity is such that the number of remanufacturables available is exactly the same as with the previous policy, i.e.:

$$s_i = \frac{s_j q_j}{q_i}.$$

The annual expected profit when procuring only from CS_i is given by:

$$E[TP_{ns}(s_i, s)] = (v - c_r + c_d)D - \left[c_b n(s) + (c_d + c_{da})s_i + c_i s_i + C\right]\frac{D}{s_i q_i}$$

$$- c_h\left(\frac{s_i q_i}{2} + s - D_L\right). \quad \textbf{(A2)}$$

Subtracting (A2) from (A1) yields:

$E[TP_{ns}(s_j, s)] - E[TP_{ns}(s_i, s)]$

$$= \left[(c_d + c_{da})s_i + c_i s_i\right]\frac{D}{s_i q_i} - \left[(c_d + c_{da})s_j + c_j s_j\right]\frac{D}{s_j q_j}$$

$$= \left[(c_d + c_{da})(s_i - s_j) + c_i s_i - c_j s_j\right]\frac{D}{s_i q_i}$$

$$= \left[(c_d + c_{da})(q_j - q_i) + c_i q_j - c_j q_i\right]\frac{s_j}{s_i q_i^2}D. \quad \textbf{(A3)}$$

By (A3) we conclude that if

$$\frac{c_d + c_{da} + c_i}{q_i} < \frac{c_d + c_{da} + c_j}{q_j}$$

then using CS_i with those s_j and s results in higher expected profits than using CS_j with its optimal s_j and s. Therefore, in the case of single sourcing it is optimal to use the CS that minimizes (3).

We now proceed to the proof of the optimality of the single sourcing policy. Assume that $(s_1, s_2, ..., s_N)$ is a vector of order quantities and that s is the respective optimal reorder point. Moreover, assume that CS_i is the CS with the minimum value of $(c_i + c_d + c_{da})/q_i$. Procuring s_i units from CS_i such that

$$s_i = \frac{\sum_{j=1}^{N} s_j q_j}{q_i}$$

and using the same value for the reorder parameter s results in the following difference in expected annual profit:

$E[TP_{ns}(s_1, s_2 ..., s_N, s)]$ - $E[TP_{ns}(s_i, s)]$

$$= \left[(c_d + c_{da}) s_i + c_i s_i \right] \frac{D}{s_i q_i} - \left[(c_d + c_{da}) \sum_{j=1}^{N} s_j + \sum_{j=1}^{N} c_j s_j \right] \frac{D}{\sum_{j=1}^{N} s_j q_j}$$

$$= \left\{ \left[(c_d + c_{da}) s_i + c_i s_i \right] - \left[(c_d + c_{da}) \sum_{j=1}^{N} s_j + \sum_{j=1}^{N} c_j s_j \right] \right\} \frac{D}{s_i q_i} \qquad \textbf{(A4)}$$

Let s_i^j denote the procurement quantities (from CS_i), which satisfy

$$s_i^j = q_j s_j / q_i$$

for j=1,…N. Since CS_i is the most preferable CS in the single sourcing case, (A3) is negative for s_j and s_i^j, j=1,2,…,N, and j≠i. Substituting $q_i s_i^j / s_j$ for q_j in (A3) and taking into account the negative sign of (A3), the following inequalities are obtained:

$$(c_d + c_{da}) s_i^1 + c_i s_i^1 \le (c_d + c_{da}) s_1 + c_1 s_1$$

$$(c_d + c_{da}) s_i^2 + c_i s_i^2 \le (c_d + c_{da}) s_2 + c_2 s_2$$

…

…

$$(c_d + c_{da}) s_i^N + c_i s_i^N \le (c_d + c_{da}) s_N + c_N s_N .$$

All the inequalities are strict except for i=j, where the inequality becomes equality. Since by definition $\sum_{j=1}^{N} s_i^j = s_i$, summation of the N inequalities yields:

$$(c_d + c_{da}) s_i + c_i s_i < (c_d + c_{da}) \sum_{j=1}^{N} s_j + \sum_{j=1}^{N} c_j s_j ,$$

which, together with (A4), proves that $E[TP_{ns}(s_1, s_2..., s_N, s)] - E[TP_{ns}(s_i, s)] < 0$. Consequently, for every possible combination of order quantities $(s_1, s_2..., s_N)$ there is an order quantity from the most profitable CS that yields higher expected annual profit. ■

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AN EMPRICAL STUDY ON SUPPLY CHAIN MANAGEMENT IN JAPANESE MANUFACTURING COMPANIES

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ABSTRACT

This paper focuses on the requirements for supply chain management (SCM) and the roles and consequences of SCM for manufacturing companies from the empirical perspective. Three measurement scales concerning SCM, coordination of plant activities, stability of demand, and supply chain planning, are found reliable and valid for thirty-five Japanese manufacturing companies. Using these measurement scales and a summarized super-scale for SCM, along with constructs of other operations areas such as human resource management, theory of constraints, quality management, total preventive maintenance, JIT production, new product development, technology development, and manufacturing strategy, interrelationships between SCM and other areas are explored. It shows that JIT production, total preventive maintenance, human resource management, theory of constraints, and some aspects of manufacturing strategy are crucial for successful SCM. In terms of the direct relationship with competitive performance, SCM occupies the most important position, followed by JIT production, total preventive maintenance, quality management, and manufacturing strategy. More specifically, supply chain planning and coordination of plant activities have strong impact on the competitive performance of the companies. The competitive performance is multi-dimensional, including cost, quality, delivery, flexibility, and service dimensions. SCM contributes to improving not only cost and service performance but also speed of new product introduction and on time new product launch.

INTRODUCTION

Supply Chain Management (SCM) has been one of the hottest areas in operations management since the late 1990s. It reflects the idea of finding a globally-maximized solution to overcome the bullwhip effect and deliver necessary items to customers at the right time. It can be regarded as a natural extension of just-in-time (JIT) and lean production philosophy, mixed with new developments in information and communication technology, logistics and theory of constraints. JIT production has been enlarged to involve direct suppliers and customers and interact with other operational activities (Schonberger, 1986; Womack et al., 1990; Harrison, 1992; Flynn et al., 1995; Monden, 1998). It is more difficult to implement SCM because any supply chain consists of many distinct members whose interests often conflict each other. Some of the key questions in SCM are how to select suppliers, how to develop collaborative relationships with suppliers and customers, and what kind information should be shared with partners in the supply chain. More recently, reflecting global concerns about environmental protection, reverse supply chain and closed-loop supply chain are being explored by practitioners and academics also (Prahinski and Kocabasoglu, 2006; French and LaForge, 2006). SCM should be more than another fad of business. It can be used as a driving force for restructuring business processes, giving managers opportunities to return to the basics of their operations and reconsider the operations policies from a macroscopic perspective. SCM needs to take in account the interfaces with the existing areas of operations management such as JIT production, theory of constraints, quality management, total preventive maintenance, human resource management, new product introduction, technology development, and manufacturing strategy. Such integrated skills and technology build up core competence of a supply chain and its partners (Hamel and Prahalad, 1994).

The main objective of this paper is to empirically analyze what requirements should be satisfied for the development of SCM, and whether the implementation of SCM can lead to improved decisions or practices in other operations areas and finally higher competitive performance. This analysis is based on the measurement scales concerning SCM and the survey data collected from Japanese manufacturing companies through extensive questionnaires in 2003 and 2004 as a part of the third round survey of High Performance Manufacturing Project.

Since an influential paper on the bullwhip effect by Lee et al. (1997), theoretical studies have been accumulated to provide various propositions or hypotheses to be tested. After entering into the 21st century, empirical research on SCM started with the development of relevant measurement scales for SCM practices to test proposed hypotheses. For instance, Li et al. (2005) proposed six constructs of SCM practices: Strategic supplier partnership; Customer relationship; Information sharing; Information quality; Internal lean practices; and Postponement. Swafford et al. (2006) develops the measurement scales on flexibility and supply chain agility. Some literature focuses on the collaborative partnership with suppliers and customers, and explores the contribution of various relationships among partners to supply chain performance (Frohlich and Westbrook, 2001; Vickery et al., 2003; Chen et al., 2004; Benton and Maloni, 2005; Li et al., 2006; Wu and Choi, 2006; Griffith et al., 2006). Our research centers on those collaborative relationships among supply chain partners as well as the internal coordination within manufacturing companies.

Further, empirical studies on the interdependence between SCM and other operations management areas have begun very recently. Christensen et al. (2005) proposes considering postponement and JIT production as predictors of supply chain knowledge and performance. Kannan and Tan (2005) explicitly addresses the linkages among JIT production, TQM and SCM, and then analyzes the impact of the linkages on business performance. Choi and Krause (2006) touches the implication of SCM to innovation. This paper intends to full explore the linkages among operational activities, which is shown in the analytical framework below.

ANALYTICAL FRAMEWORK AND HYPOTHESES

Figure 1 shows an analytical framework with four major building blocks to assess the real value of SCM for Japanese manufacturing companies: (1) human resource management and organization; (2) quality management, total preventive maintenance, theory of constraints, JIT production, and supply chain management; (3) technology development, new product development, and manufacturing strategy; (4) competitive performance. Organization together with human resource management provides an infrastructure on which elaborate manufacturing systems are established and manufacturing strategy is formulated. The second block consists of core manufacturing operations systems concerning quality, inventory, production planning, and information flow within manufacturing companies and throughout the supply chain. The third block includes more technological and strategic aspects of operations, which are closely related each other and interact with core manufacturing operations systems. These three blocks are put together to determine the competitive performance of manufacturing plants.

This paper centers on SCM within the framework, and explores its relationship with human resource management, organization, theory of constraints, quality management, total preventive maintenance, new product development, technology development, manufacturing strategy, and competitive performance. It is assumed that SCM is a key factor determining competitive performance not merely directly but also indirectly through the impact upon other manufacturing practices and strategy. The following two general hypotheses are to be tested:

Hypothesis 1: SCM interrelates with human resource management, theory of constraints, quality management, total preventive maintenance, JIT production, technology development, and manufacturing strategy.

Hypothesis 2: SCM contributes to competitive performance of the company.

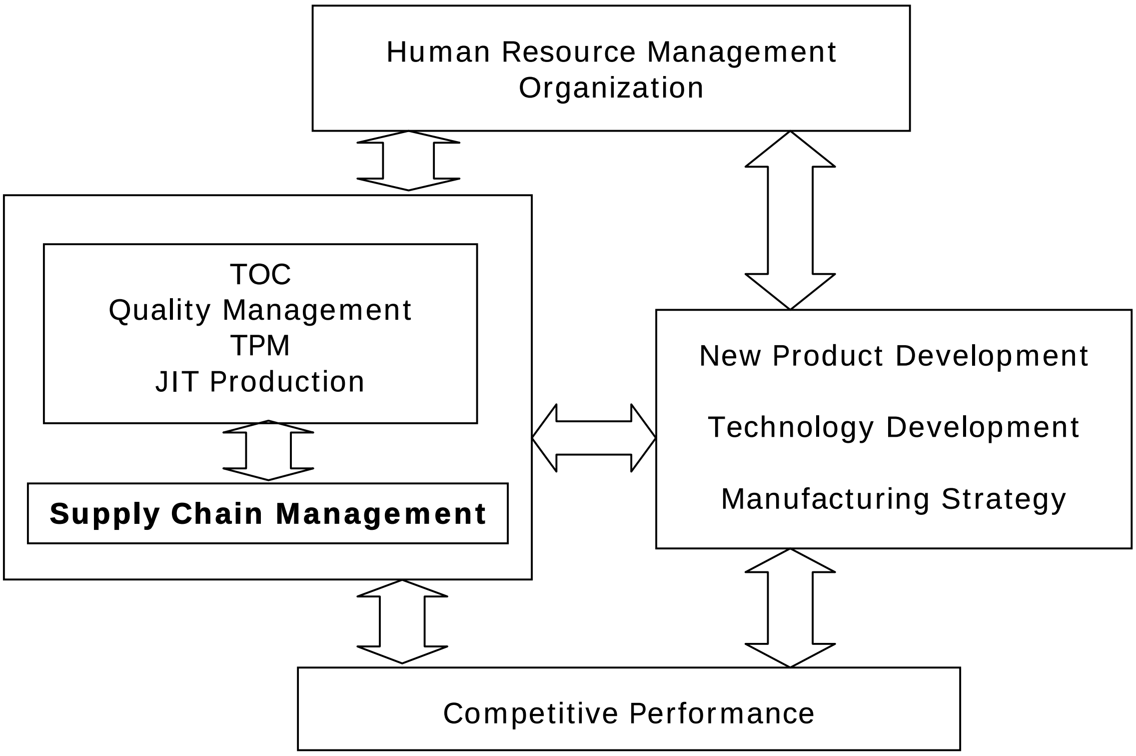

Figure 1: Analytical framework for high performance manufacturing

RESEARCH VARIABLES

In order to make operationalize the analytical framework and the hypotheses in the preceding section, research variables below are introduced. They are divided into four categories.

SCM measurement scales

The first set of variables is concerned with SCM from the perspective of manufacturing companies. To measure several practices on SCM the following five scales are proposed:

1) *Coordination of Plant Activities* (CPA) measures the restriction of managerial decision making space due to corporate policies or action. It focuses on coordination between corporate and plant activities.
2) *Stability of Demand* (SOD) assesses whether manufacturing demands have been stabilized in cooperation with sales department in demand forecasting.
3) *Supply Chain Planning* (SCP) evaluates whether the company has occupied a dominant position in planning and controlling the supply chain to customers.
4) *Supplier Lead Time* (SLT) measures whether the company is taking measures to reduce supplier lead time and avoid excess inventory and stock-out risk.
5) *Trust-Based Relationship with Suppliers* (TBR) measures the level of belief in beneficial collaboration with suppliers.

Each measurement scale is constructed by several question items evaluated on a seven-point Likert scale (1=Strongly disagree, 2=Disagree, 3=Slightly disagree, 4=Neutral, 5=Slightly agree, 6=Agree, 7=Strongly agree). More precisely, four to seven question items are used to construct the measurement scales. Individual question items are shown in the appendix.

Other measurement scales

The second category of variables consists of measurement scales in the areas of organization, human resource management, quality management, production information systems, technology development and manufacturing strategy. Each measurement scale is a construct using several question items measured on a five-point Likert scale. The list of respective measurement scales is as follows:

1) Human resource management
   Cooperation; Coordination of decision making; Employee suggestions; Commitment; Flatness of organization structure; Human goodness; Management breadth of experience; Multi-functional employees; Recruiting and selection; Supervisory interaction facilitation; Small group problem solving; Shop floor contact; Task-related training for employees; Centralization of authority; Rewards/manufacturing coordination
2) Theory of constraints
   TOC philosophy; Implementation of TOC
3) Quality management
   Cleanliness and organization; Customer focus; Customer involvement; Customer satisfaction; Organization-wide approach; Prevention; Process emphasis; Feedback; Process control; Supplier quality involvement; Top management leadership for quality; TQM link with customers; Supplier partnership
4) Total preventive maintenance
   Autonomous Maintenance; Maintenance Support; Team Based Maintenance; Preventive Maintenance
5) JIT production
   Daily schedule adherence; Equipment layout; Just-in-time delivery by suppliers; Just-in-time link with customers; Kanban; Repetitive nature of master schedule; Setup time reduction; Small lot size; Synchronization of operations
6) New product development
   Customer Involvement; Project Complexity; Manufacturing Involvement in New Product Development; Project Priority; Team Rewards; Team Spirit; Supplier Involvement
7) Technology development
   Effective process implementation; Inter-functional design efforts; Mass customization; Modularization of products; New product introduction cooperation
8) Manufacturing strategy
   Achievement of functional integration; Anticipation of new technologies; Communication of manufacturing strategy; Competitive intensity of industry; Formal strategic planning; Integration between functions; Leadership for functional integration; Manufacturing as a competitive resource; Manufacturing-business strategy linkage; Proprietary equipment; Unique practices

Super-scales for main areas of production management

In the analysis below, super-scales are introduced to summarize the measurement scales in the following areas of production management: *Human resources management* (HR), *Quality management* (QM), *Total preventive maintenance* (TPM), *Theory of constraints* (TOC), *Just-in-time production* (JIT), *Supply chain management* (SCM), *New product development* (NPD), *Technology development* (TECH), and *Manufacturing strategy* (MS).

Performance indicators

The last set of variables is concerned with competitive performance indicators relative to global competitors in the industry. Each plant manager subjectively judges them on a five-point Likert scale (1=Poor or low end of the industry, 2=Below average, 3=Average, 4=Better than average, 5=Superior or top of the industry). The following thirteen performance indicators cover the basic objectives in the production function, that is, cost, quality, delivery, and flexibility: Unit cost of manufacturing; Quality of product conformance; Delivery performance; Fast delivery; Flexibility to change product mix; Flexibility to change volume; Inventory turnover; Cycle time; Speed of new product introduction; Product capability and performance; On time new product launch; Product innovativeness; Customer support and service. Objective performance indicators were also collected from each plant. They do not necessarily reflect the actual competitiveness of each plant, however, because of high variability in demand pattern, product complexity, and process technology.

DATA COLLECTION METHODS

Data for this analysis was collected through the international collaboration on high performance manufacturing (HPM) in 2003 and 2004 as the third round survey for Japanese manufacturing companies. The data is comparable to those data from the second round survey conducted in mid-1990s, whose analytical results are shown in Schroeder and Flynn (2001). The third round survey includes data from thirty-five Japanese manufacturing companies, while the second round survey had forty-six plants, both from machinery, electrical & electronics, and automobile industries. In all plants nineteen individuals across levels responded to twelve different types of questionnaires that partially share the questions in the third round. Those numbers were reduced from twenty-six persons and fifteen types of questionnaires. The respondents in the third round include a plant manager, a plant superintendent, a plant accountant, a human resource manager, an inventory manager, an information systems manager, a production control manager, a process engineer, a quality manager, a member of new product development project, four supervisors and direct labor. Plant-level data are calculated as an average value of all the valid responses at the company for each qualitative question item.

Those respondents were asked to answer around one hundred question items most of which are included to construct measurement scales for SCM as well as other manufacturing practices and strategy. A plant superintendent, an inventory manager, four supervisors were asked to answer the question items for all of five SCM scales.

RESULTS OF ENPIRICAL ANALYSIS

Results from the data analysis are shown in the four sections below. on measurement scales, comparison across industries of below. The analysis was done with SAS version 9 and SPSS version 14.

Measurement analysis of SCM scales

A starting point is the measurement analysis of five measurement scales proposed on SCM. The reliability of measurement scales is usually judged according to the Cronbach's alpha coefficient, which should be more than 0.6 for a newly developed scale. The validity of measurement scales is tested against content, construct, and external criteria. Construct validity can be examined through factor analysis, where uni-dimensionality and factor loadings of more than 0.4 are essential checkpoints. These analyses are applied to the individual-level data for 35 Japanese manufacturing companies. The methodological issues on empirical research in operations management are discussed by Flynn *et al*. (1990) for instance. Matsui (2001, 2002, and 2006) reports the measurement analysis for information systems quality management, technology development, manufacturing strategy and JIT production in Japanese plants.

As shown in Table 1, only the first three measurement scales meet the criteria for reliability and validity. Note that initially two factors are found to be principle for *Stability of demand* and *Supply chain planning*. By dropping the last question item with the lowest factor loadings *Supply chain planning* can clear the criteria quickly. *Stability of demand* becomes marginally reliable, however, after removing three question items related to demand forecasting leaves two question items only. The remaining question items are simply averaged to obtain the scores for each scale. Reliable scales cannot be constructed for *Supplier lead time* and *Trust-based relationship with suppliers*.

Table 1: Reliability and validity (all plants, individual-level data)

Scale	CPA	SOD			SCP		
alpha coefficient:	0.7559	0.4862		0.7003	0.7222		0.7887
Factor loadings:	Factor1	Factor1	Factor2	Factor1	Factor1	Factor2	Factor1
Question item 1	0.543	0.609	0.490	deleted	0.752	–0.376	0.771
Question item 2	0.747	0.787	-0.366	0.878	0.696	-0.355	0.713
Question item 3	0.753	0.425	0.725	deleted	0.786	-0.127	0.788
Question item 4	0.699	0.759	-0.405	0.878	0.572	0.332	0.560
Question item 5	0.805	-0.044	0.260	deleted	0.815	0.113	0.808
Question item 6	0.514				0.552	0.217	0.542
Question item 7					0.279	0.815	deleted
Eigenvalue:	2.820	1.748	1.130	1.541	3.043	1.117	2.983
Proportion:	47.00%	34.95%	22.61%	77.04%	43.47%	15.95%	49.17%
No. of factors:	1	2		1	1		1

Scale	SLT		TBR
alpha coefficient:	0. 4833	0.5279	0.5816
Factor loadings:	Factor1	Factor1	Factor1
Question item 1	0.730	0.754	0.734
Question item 2	0.634	0.646	0.524
Question item 3	0.346	deleted	0.772
Question item 4	0.742	0.756	0.646
Eigenvalue:	1.605	1.558	1.826
Proportion:	40.13%	51.92%	45.64%
No. of factors:	1	1	1

Further, a super-scale on SCM is established through averaging the reliable and valid measurement scales. Using the plant-level data, the super-scale, *SCM*, is proved reliable and valid, which demonstrates the close relationships among the nine measurement scales. Although the value of Cronbach's alpha coefficient, 0.7369, is not very high, only one potent factor is abstracted, whose loadings are 0.894 for *Coordination of plant activities*, 0.834 for *Stability of demand*, and 0.689 for *Supply chain planning*.

Table 2: Mean values of SCM scales

Scale	MACH	ELEC	AUTO	F	All
Coordination of plant activities	4.10	4.39	4.80	3.38*	4.44
Stability of demand	3.64	3.89	4.45	4.66*	4.01
Supply chain planning	4.50	4.95	4.90	2.50	4.78
SCM (super-scale)	4.08	4.41	4.71	5.17*	4.41
Sample size	12	10	13		35

* significant at 5% level by one-tailed test

Comparison across industries

This section discusses industry effects on SCM, using analysis of variance technique. Demand patterns and product features may influence the effectiveness of supply chain integration and the penetration of SCM thinking. Compared are three manufacturing industries: machinery, electrical & electronics, and automobile.

Table 2 shows that there is significant inter-industry difference in the mean value of *Coordination of plant activities*, *Stability of demand*, and also *SCM* super-scale. Coordination performed by the corporate headquarters functions best in automobile companies, partly because they have relatively homogeneous activities across plants. Also those automobile companies are the most effective to control demand, which is to make other SCM practices easy to accomplish. Electrical & electronics companies try to plan and control the entire supply chain as well as automobile companies to flexibly meet changing requirements of customers. For these scales, automobile companies mark the largest average value. This test is based upon the normality of the relevant populations. The Shapiro-Wilk's test cannot reject the hypothesis that a sub-sample is randomly selected from a normal population even at the 10% level for any SCM scales.

Table 3: SCM scales and competitive performance indicators

	First canonical variable
Canonical correlation	0.9000
Likelihood ratio	0.0559
Significance	0.0336
Redundancy index: SCM	0.5536
Redundancy index: performance	0.1722
Correlations between SCM scales and canonical variable of competitive performance indicators	
Coordination of plant activities	0.7503
Stability of demand	0.8382
Supply chain planning	0.5086
Correlations between competitive performance indicators and canonical variables of SCM scales	
Unit cost of manufacturing	0.4149
Quality of product conformance	0.1609
Delivery performance	0.3067
Fast delivery	0.3275
Flexibility to change product mix	0.2487
Flexibility to change volume	0.4315
Inventory turnover	0.5340
Cycle time	0.1735
Speed of new product introduction	0.5711
Product capability and performance	0.2299
On time new product launch	0.5824
Product innovativeness	0.3422
Customer support and service	0.4543

SCM and competitive performance

This section tests the hypothesis 2, that is, the relationship of SCM with competitive performance. A canonical correlation analysis between three SCM scales and competitive performance indicators proves that all the SCM scales. Particularly *Stability of demand* and *Coordination of plant activities* have widespread impacts on performance indicators with respect to speed of new product introduction, on time new product launch, Inventory turnover, customer support and service, flexibility to change production volume, unit cost of manufacturing, as shown in Table 3. A special notice should be given to the fact that SCM contributes to improving the two important time performance indicators in the area of new product development. The first canonical correlation is 0.9, and the likelihood ratio shows high significance. According to the redundancy index, around 17% of variance of the competitive performance indicators is explained by the canonical variable of the SCM scales.

Even if the three SCM scales are replaced by nine super-scales in order to determine the role of JIT production from a wider perspective, the redundancy index remains nearly unaffected, and canonical correlation model becomes less significant, as shown in Table 4. This means that the SCM scales are as powerful to explain the variability of competitive performance as the nine super-scales. The direct impact of *SCM* on competitive performance indicators is relatively strong. In terms of the correlation with the first canonical variable of competitive performance indicators, *SCM* occupies the top position, followed by *JIT*, *TPM*, *QM*, and *MS*.

Table 4: Super-scales and competitive performance indicators

	First canonical variable
Canonical correlation	0.9732
Likelihood ratio	0.00004
Significance	0.0715
Redundancy index: super-scale	0.3816
Redundancy index: performance	0.1852
Correlations between super-scales and canonical variable of competitive performance indicators	
Human resource management (HR)	0.4963
Theory of constraints (TOC)	0.5673
Quality management (QM)	0.6577
Total preventive maintenance (TPM)	0.7094
Just-in-time production (JIT)	0.7350
Supply chain management (SCM)	0.7772
New product development (NPD)	0.3281
Technology development (TECH)	0.5812
Manufacturing strategy (MS)	0.6568
Correlations between competitive performance indicators and canonical variable of super-scales	
Unit cost of manufacturing	0.4501
Quality of product conformance	0.1845
Delivery performance	0.2300
Fast delivery	0.1548
Flexibility to change product mix	0.2798
Flexibility to change volume	0.4248
Inventory turnover	0.7994
Cycle time	0.3205
Speed of new product introduction	0.5986
Product capability and performance	0.1369
On time new product launch	0.5044
Product innovativeness	0.3765
Customer support and service	0.3494

These results for the Japanese manufacturing companies strongly support the hypothesis 2 that the implementation of SCM through the coordination with corporation, demand control, and supply chain planning strengthens the competitive position of the company. One of the most important factors for competitiveness of recent Japanese manufacturing sector can be attributed to supply chain management, JIT production, and the various practices and capabilities to advance the existing production system further. It might be the case in the 1980s, while most Japanese manufacturing companies shifted their focuses towards manufacturing strategy, technology development, and new product development and introduction in the 1990s, facing the bursting of the bubble economy and the rapid growth of manufacturing in other Asian countries. Some of them restructured their businesses, and outsourced manufacturing operations to the third party. Recently in a little favorable market conditions, high performance Japanese manufacturers try to return to the basics of manufacturing operations, recover their lost operational competitiveness, and establish new capabilities by combining collaborative supply chain, efficient JIT production, innovative new products, and sophisticated strategic planning and implementation all together. That is a reason why the relationships between SCM and other operations management areas should be well explored.

SCM and other operations management practices

The final part of analysis is concerned with the hypothesis 1 and look into the relationship among operations management practices to find out requirements or facilitators for SCM and its influence on other important operations areas. Simple correlation coefficients between the super-scales on operations management, as shown in Table 5, are all significantly more than zero except between *NPD* and others. *SCM* is closely correlated with all of *JIT* (0.80), *TPM* (0.79), *HR* (0.75), *TOC* (0.69), *MS* (0.67), *TECH* (0.63), and *QM* (0.63).

Table 5: Correlation coefficient between super-scales

	SCM	HR	TOC	QM	TPM	JIT	NPD	TECH
HR	0.7472							
TOC	0.6866	0.6873						
QM	0.6296	0.6996	0.6542					
TPM	0.7920	0.8819	0.7754	0.7748				
JIT	0.8017	0.7007	0.7032	0.5781	0.7859			
NPD	0.2459	0.2359	0.3247	0.2608	0.3123	0.3324		
TECH	0.6301	0.6057	0.6067	0.7216	0.7680	0.6583	0.4079	
MS	0.6700	0.6936	0.6747	0.6855	0.7669	0.5776	0.1909	0.7323

These relationships can be explored further by using canonical correlation techniques into the level of measurement scale. Table 6 summarizes the result of a series of canonical correlation analyses between the three SCM scales and measurement scales for other operations areas. In every case except with new product development scales, the first canonical correlation is more than 0.8, much higher than the corresponding simple correlation coefficient, and is judged to be significant by the likelihood ratio test except the canonical correlation between SCM and new product development scales (p=0.4065). The redundancy index for SCM is more than forty percent as explained by the first canonical variable of human resource management, JIT production, total preventive maintenance, and manufacturing strategy scales. The redundancy index explained by the first canonical variable of the SCM scales is more than forty percent for theory of constraints, total preventive maintenance, and JIT production scales, which demonstrates the extensive impact of SCM. Practices. This analysis suggests the direction of influence between SCM and other operations areas. SCM has interdependent relationships with total preventive maintenance, JIT production, human resource management, and manufacturing strategy. On the other hand, the influence of theory of constraints on SCM is less than the opposite.

Table 6: Summary of canonical correlation analysis between SCM and other operation management areas (the first canonical correlation variable only)

	HR	TOC	QM	TPM	JIT	NPD	TECH	MS
Canonical correlation	0.9281	0.8155	0.8067	0.8643	0.9240	0.6330	0.8109	0.8678
Likelihood ratio	0.0587	0.3342	0.1235	0.1626	0.0498	0.4068	0.3093	0.1369
Significance	0.0193	0.0001	0.0801	0.0001	0.0001	0.4065	0.0029	0.0201
Redundancy index (SCM)	0.5176	0.3317	0.2678	0.4584	0.4629	0.1699	0.3843	0.4325
Redundancy index (other)	0.3418	0.6314	0.1357	0.5698	0.4565	0.0865	0.2765	0.3243

More precisely, the first canonical variable of SCM scales is closely related to the following twenty-two scales: *Small group problem solving* (0.7517), *Rewards/ manufacturing coordination* (0.7486), *Coordination of decision making* (0.7314), *Recruiting and selection* (0.7008), *Shop floor contact* (0.7006), and *Supervisory* *interaction facilitation* (0.7000) from human resource management; *Implementation of TOC* (0.7987) and *TOC philosophy* (0.7905) from theory of constraints; *Preventive Maintenance* (0.8176), *Maintenance Support* (0.7813), and *Team Based Maintenance* (0.7767) from total preventive maintenance; *Synchronization of operations* (0.8589), *Equipment layout* (0.8230), *Setup time reduction* (0.8116), *Daily schedule adherence* (0.7902), *Just-in-time delivery by suppliers* (0.7576), *Just-in-time link with customers* (0.7724), and *Repetitive nature of master schedule* (0.7250) from JIT production; *Effective process implementation* (0.7957) and *Inter-functional design efforts* (0.7129) from technology development; *Leadership for functional integration* (0.7560) and *Unique practices* (0.7290) from manufacturing strategy. Figures in parentheses represent the correlations with the first canonical variable of SCM scales. Those practices are regarded as requisites for SCM implementation.

Human resource management including organizational characteristics strongly correlate with such SCM practices as *Coordination of Plant Activities* (0.8714) and *Supply Chain Planning* (0.6813) as a communication infrastructure to keep enlarging the problem solving competence.

Theory of constraints approach serves as a prerequisite for formulating *Supply Chain Planning* (0.6993), while total preventive maintenance has impact on SCM practices such as *Coordination of Plant Activities* (0.7660) and *Supply Chain Planning* (0.6993). Likewise, JIT production has a close relationship with *Supply chain plannin*g (0.8164) and *Coordination of plant activities* (0.7571).

The New product development is modestly correlated with SCM scales, 0.5441 with *Coordination of Plant Activities* and 0.4625 for *Supply Chain Planning*, although the supply chain for new products is critical to most manufacturers and SCM promotes the competitive performance in new product development. Technology development in terms of product and process design and implementation has interrelated with SCM practices such as *Coordination of Plant Activities* (0.6995) and *Supply Chain Planning* (0.6828). The impact of SCM upon technology development was more dominant than the reverse for the second round data. In the same way, the first canonical variable of the manufacturing strategy scales is closely related to *Coordination of Plant Activities* (0.7853) and *Supply Chain Planning* (0.6844). The relationships are reasonable, because those SCM practices are typical examples of unique practices the companies are trying to establish. Implementing SCM definitely needs a strategic perspective and occupies an important part of manufacturing strategy.

In summary these results for the Japanese manufacturing companies basically support the hypothesis 1 that SCM interacts with human resource management, quality management, total preventive maintenance, theory of constraints, JIT production, technology development, and manufacturing strategy. Although the relationships with quality management are marginal, other pairs are highly linked each other so as to construct operational capabilities. SCM is the pivotal driving force for restructuring operations inside and relationships with suppliers and customers in the Japanese manufacturing companies.

CONCLUSIONS

This paper proposes an analytical framework for high performance manufacturing and focus on two hypotheses on the requirements for and the roles of SCM. Then, it reports three reliable and valid measurement scales concerning practices on SCM, using the data collected from thirty-five Japanese manufacturing companies in 2003 and 2004. Using these scales and a summarized super-scale, a series of analyses are done for the relationships of SCM with other operations areas and competitive performance. The main findings are as follows:

a) SCM strongly interrelates with other operations areas such as human resource management, theory of constraints, quality management, total preventive maintenance, JIT production, technology development, and manufacturing strategy. Twenty-two scales are judged to be especially important prerequisites or consequences of SCM. Those scales jointly characterize high problem-solving capabilities of each individual and group, a solid base for quality management and preventive maintenance, advancements in theory of constraints, efficient JIT and lean production, collaborative product and process technology development, and manufacturing strategy encouraging functional integration as well as unique practices. *Coordination of Plant Activities* and *Supply Chain Planning* among the SCM scales are highly related with many operations areas.

b) SCM strongly contributes to competitive performance. Especially, *Stability of demand* and *Coordination of Plant Activities* have strong impact upon the competitive position of the manufacturing companies. It directly affects the competitive performance regarding new product development time.

c) In terms of the strength of the direct relationship with competitive performance, SCM occupies the top position, followed by JIT production, which is regarded as a favorable condition for implementing SCM.

SCM, along with JIT production, plays a pivotal role for manufacturing operations in Japan. SCM and JIT production strongly interrelate with human resource management, theory of constraints approach, quality management initiatives, product and process technology development, and manufacturing strategy formulation and implementation. A lot of operational practices are linked together. Most Japanese companies have been accumulating their capabilities to exploit this linkage structure and the synergy effects among different operations areas to attain sustainable competitiveness in the global market. A pair of SCM and JIT production is regarded as one of key linking nodes. Our analysis reveals that those Japanese manufacturers return to the basics of their operations after restructuring and outsourcing their businesses and while introducing a lot of new products into the market.

Finally, there are possibilities to extend our research further in some directions. More comprehensive structure to determine manufacturing performance should be drawn and analyzed. The same methodology adopted in this paper could be applied to other operations management areas, and then those results be amalgamated. This paper uses a sample consisting of thirty-five manufacturing companies located in Japan, which clearly limits the availability of analytical techniques. The sample size problems might be solved when the data for manufacturing companies in other countries are pooled with the Japanese sample. Another research direction in the future is a comparative analysis of SCM, using data from US, European and Asian manufacturing companies.

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APPENDIX: QUESTION ITEMS FOR SCM SCALES

1) *Coordination of Plant Activities*

   1. Purchasing of common materials is coordinated at the corporate level.
   2. Our corporation implements ordering and stock management policies, on a global scale, in order to coordinate distribution.
   3. Our corporation performs aggregate planning for plants, according to our global distribution needs.
   4. Managerial innovations are transferred among plants within our corporation.
   5. Our corporation transfers technological innovations and know-how between plants.
   6. The choice of information systems standards and technologies for plants is coordinated at the corporate level.

2) *Stability of Demand*

   1. Sales and manufacturing personnel communicate well with each other in this organization.
   2. Manufacturing demands are stable in our firm.
   3. Our inventory fluctuates more than planned.
   4. Our total demand, across all products, is relatively stable.
   5. We need better accuracy in our demand forecasts.

3) *Supply Chain Planning*

   1. We actively plan supply chain activities.
   2. We consider our customers’ forecasts in our supply chain planning.
   3. We strive to manage each of our supply chains as a whole.
   4. We monitor the performance of members of our supply chains, in order to adjust supply chain plans.
   5. We gather indicators of supply chain performance.
   6. We share our production plans with our suppliers.
   7. Our customers do not have access to our production plans.

4) *Supplier Lead Time*

   1. We seek short lead times in the design of our supply chains.
   2. We purchase in small lot sizes, to reduce supplier lead time.
   3. When outsourcing, we consider supplier lead time as a greater priority than cost.
   4. Our company strives to shorten supplier lead time, in order to avoid inventory and stock-outs.

5) *Trust-Based Relationship with Suppliers*

   1. We are comfortable sharing problems with our suppliers.
   2. In dealing with our suppliers, we are willing to change assumptions, in order to find more effective solutions.
   3. We believe that cooperating with our suppliers is beneficial.
   4. We emphasize openness of communications in collaborating with our suppliers.

Facility Integration Problem for Resource Recycle

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ABSTRACT

Generally, in the case of some recycling facilities located on a region area, if decrease of inhabitants or amount of recycled resource is happen, stopping of some facilities will be decided by the regional government or a public corporation. The area of the stopped facility should be integrated to other area that the recycling facilities are operating. Choice of facilities stopping the use and integration of the area are essence of this problem. In this study, this problem is formulated as an assignment problem considering recovery. For each facility, fixed cost, variable cost, capacity per period and the decrease of volume of recycled resource by stopping the facility and integration to a facility of other area are given. In this problem, under the total cost constraint, it is carried out to decide the stopped facilities and integrate to other operating facility to maximize the amount of recycled resource. If the number of facilities is more than ten, the optimum is not able to find by enumeration of all alternatives. For solving this assignment problem, we proposed an evolutionary algorithm that improves the solution from initial one as present setting to excellent solution by a new evolutionary searching method.

INTRODUCTION

Recently, the global environment is regarded as important in various fields; it is similar in production and material flow activities. There is much plant and equipment investment for recovery, recycling and reuse of resources, as the measure that considered environment. However, a tendency of a population decline is strengthened in some countries and may show a low growth rate in much situation. Accordingly, it is forecasted that some recycling facilities do not well in economical operation. In this study, for such situation, modelling of integration problem of old recycling facilities which minimized decrease of quantity of resource recovery under cost constraint.

PROBLEM DEFITION

A regional government bureau or a public corporation divide the territory that performed recycling resource in *n* zones, and one recycle facility is sited in each zone. It is decided a next budget to be reduced than a total cost for this term. Some facilities should be integrated to other facility for deceasing to the total cost. However, amount of recycled resource should be maximized under the constraint of budget of next term.

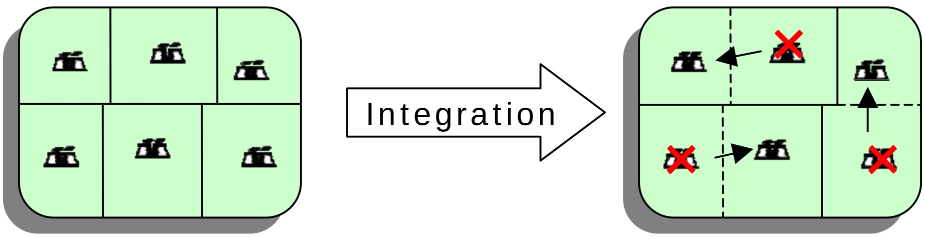

Figure 1 Integration of facilities

If Facility i in Zone i is stopped and Facility i is integrated to Facility j in other Zone j, it is assumed that the recovery rate $r(i, j)$ is known. In the condition, stopped facilities should be decided to maximize amount of recovered resource under the cost constraint $C_{\max}$.

In this problem, stopped facilities are decided and the stopped facility is integrated to other running facility. To represent these conditions, following binary variables are introduced:

$$x(i)=\begin{cases}1, & \text{Facility } i \text{ is runnnig}\\ 0, & \text{Facility } i \text{ is stopped}\end{cases}$$

$$y(i,j)=\begin{cases}1, & \text{Facitity } i \text{ is integrated to Facility } j\\ 0, & \text{Facitity } i \text{ is not integrated to Facility } j\end{cases}$$

In this manner, running facility is not integrated, and stopped facility must be integrated to other one facility. This relation is represented by following expression:

$$\sum_{j=1}^{n} y(i,j)=\begin{cases}0, & \text{if } x(i)=1\\ 1, & \text{if } x(i)=0\end{cases}$$

As the objective function, the equation of total amount of recovered resource at after the integration is adopted, and the value of objective function should be maximized. As constraints, total cost can not over cost constraint $C_{\max}$, amount of recovered resource at each running facility can not over the capacity of the facility $q_{\max}(i)$. By mentioned above condition, this problem is represented as following model:

$$\max \quad \sum_{i=1}^{n} p(i)\,x(i)$$

Subject to

$$\sum_{i=1}^{n} (c_f(i)\,x(i)+c_v(i)\,p(i)) \le C_{\max}$$

$$C_{\max} < \sum_{i=1}^{n} (c_f(i)+q(i)c_v(i))$$

$$p(i) \le q_{\max}(i), \quad i=1,\dots,n$$

$$\sum_{j=1}^{n} y(i,j)+x(i)=1, \quad i=1,\dots,n$$

$$x(i)\in\{0,1\}, \quad i=1,\dots,n$$

$$y(i,j)\in\{0,1\}, \quad i,j=1,\dots,n, i\ne j$$

$$y(i,j)=0, \quad i=j$$

Where

$C_f(i)$ = fixed cost of Facility i

$C_v(i)$ = variable cost of Facility i

$p(i)$ =recovery amount of Facility i at after the integration

$q(i)$ =recovery amount of Facility i at before the integration

$r(i, j)$ =recovery rate of the case of Facility i is integrated to Facility j ,

$$0 < r(i, j) \leq 1$$

NUMERIC EXAMPLE

To demonstrate of the proposed model, an example of six facilities (see Tables 1 and 2) is used for computation experiment.

Table 1 Example of facility data (n=6)

	Facility i					
	1	2	3	4	5	6
$q_{max}(i)$ [t]	200	160	150	180	190	170
$q(i)$ [t]	70	55	60	70	70	65
$c_f(i)$ [10^5yen]	1000	700	700	850	1000	850
$c_v(i)$ [10^5yen/t]	10	20	20	15	10	15

Table 2 Example of recovery ratio after the integration of facility i to j (n=6)

i \ j	1	2	3	4	5	6
1	1.00	0.90	0.20	0.90	0.30	0.10
2	0.90	1.00	0.85	0.50	0.85	0.50
3	0.50	0.90	1.00	0.10	0.30	0.90
4	0.90	0.60	0.10	1.00	0.85	0.50
5	0.50	0.90	0.90	0.90	1.00	0.90
6	0.10	0.60	0.20	0.20	0.85	1.00

By enumeration method, 878 integration alternatives are found in the example mentioned above. In Figure 2, those alternatives are plotted at a graph of total cost and recovery amount.

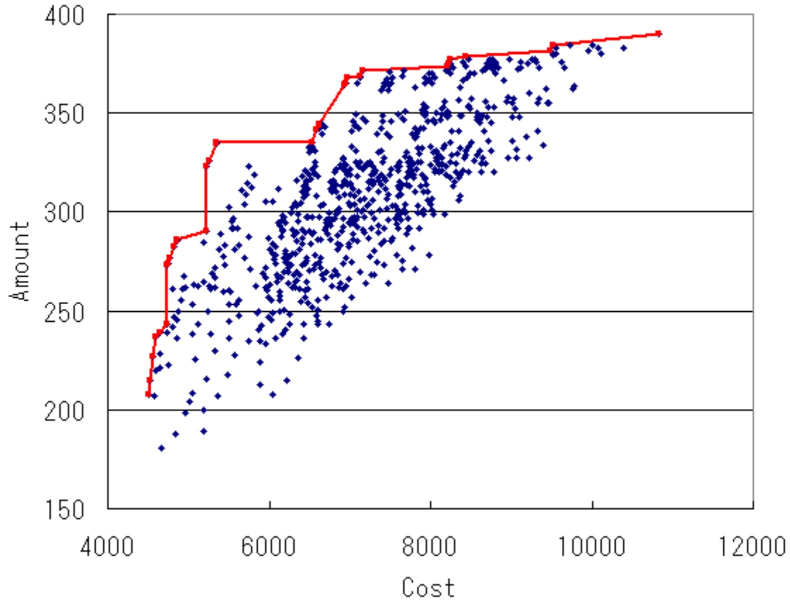

Figure 2 Graph of plot with cost and recovery amount

Furthermore, maximum value of recovery amount at the cost is found, and those plots are joined by line. This curve is inspired from the Cost Performance Curve by Kusaka(1998).

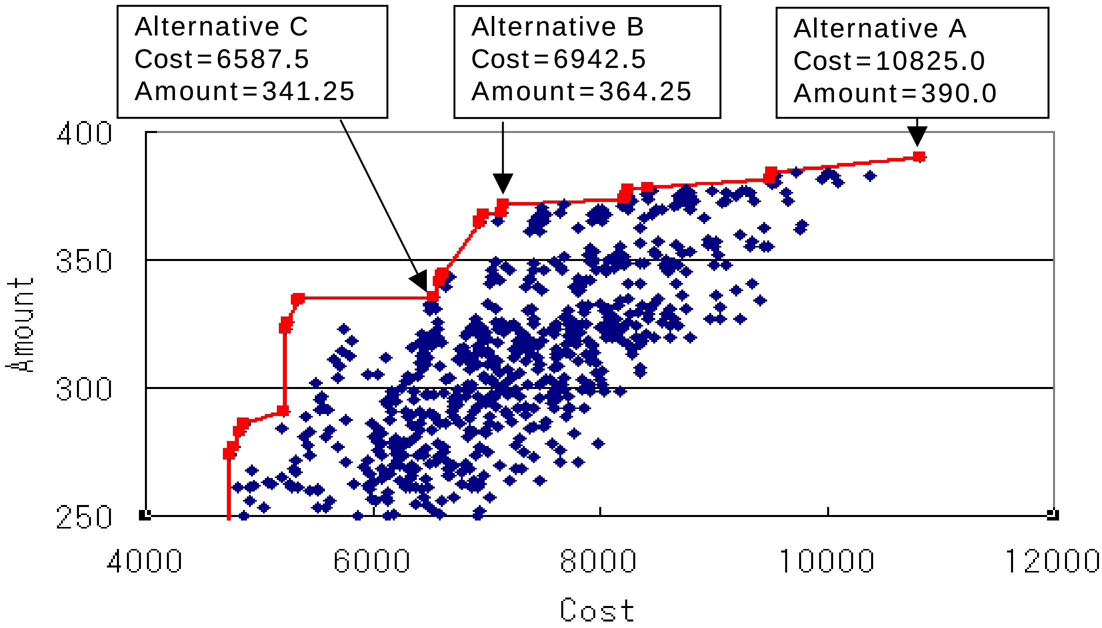

Figure 3 Comparison of integration alternatives

In this case, Alternative A is the current facilities (stopped facility is nothing), uses 10825.0x10^5yens. Alternative B can process recovered resource of 364.25 tons and uses cost of 6942.5 x10^5yens, amount and cost of Alternative C are 341.25 tons and 6587.5 x10^5yens. The efficiency of Alternative B is similar to the value of Alternative C. If cost constraint C_{max} =6600 x10^5yens, Alternative C is chosen. However, when the budget is flexible in the range of plus 5%, Alternative B is a preferable plan, because decease of amount from Alternative A is smaller than Alternative C. In this example, decision should be made to choose Alternative B.

SEARCH METHOD

In the case of number of facility is less than 10, enumeration method is available (see Table 3).

Table 3 Results of computation time.

Number of facility	Computation time[sec.]
6	1.5
7	11.0
8	82.4
9	1176.4

Pentium IV 3.4GHz, RAM1.25GM,
Windows XP Pro., BCC++5.5

If number of facility is greater than 9, enumeration is not effective. Other search method is necessary to solve in practical computation time. This problem is a kind of assignment problem, it is difficult to solve large scale problem by exact solving methods.

In such case, heuristic method is often used to solve the problem, *e.g.* Suzuki *et al.* (2006). In this study, an evolutionary algorithm is developed (Figure 4).

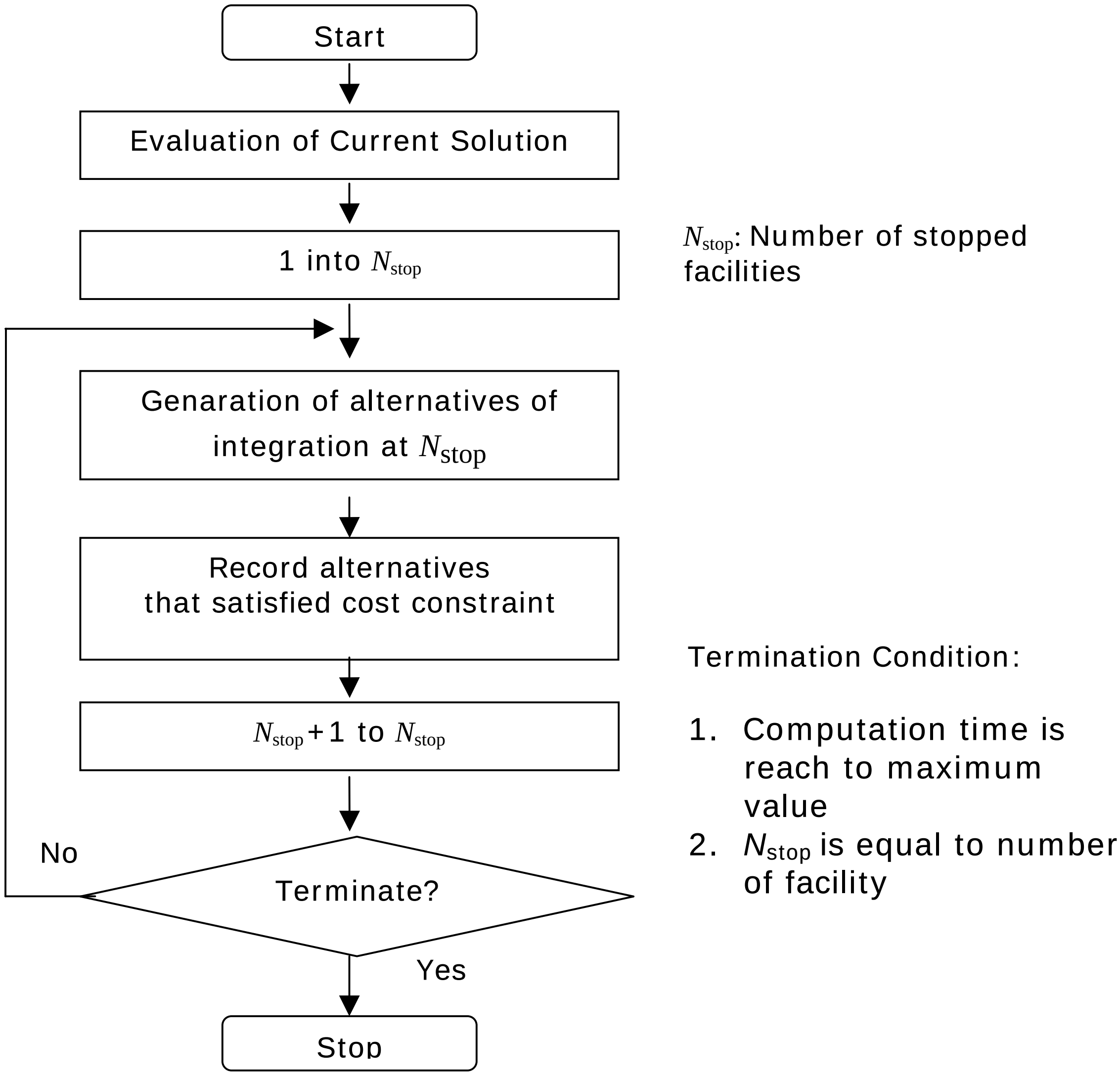

Figure 4 Proposed evolutionary algorithm

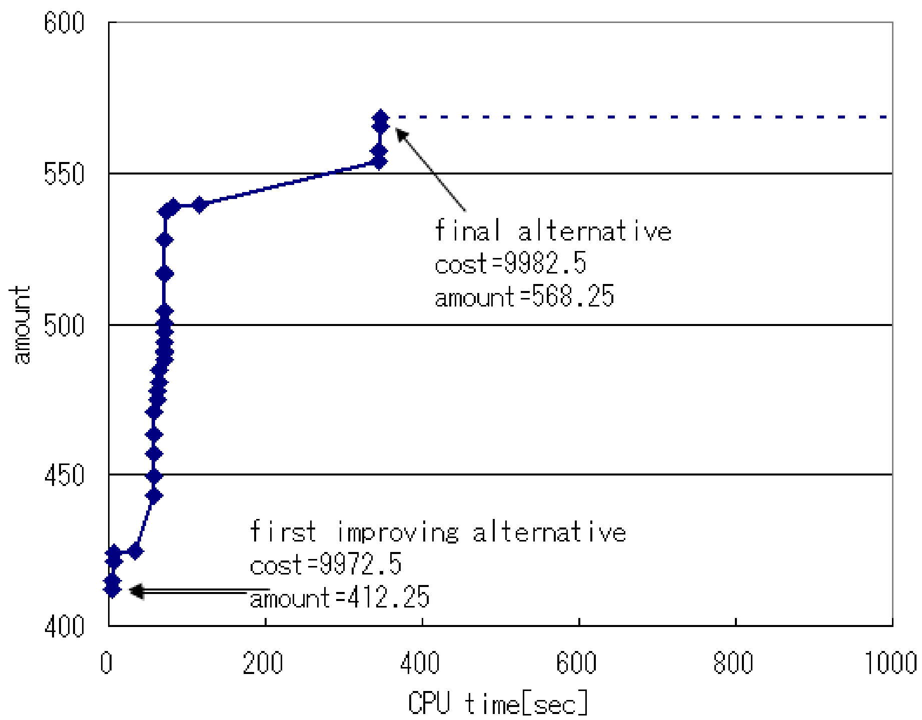

Figure 5 Calculation result of example (n=10)

The calculation result of solving example of ten facilities integration problem by proposed evolutionary algorithm is shown in Figure 5. Those plots are alternatives that costs constrain are satisfied, computation maximum time is 1000sec., and cost constraint is 10000×10^5yens. The first improved alternative is the number of stopped facility (N_{stop}) =5, cost=9972.5, amount=412.25. At the final alternative, Nstop=6, cost=9982.5, amount=568.25, the solution is certainly improved.

CONCLUSION

In this paper, a new model for integration of recycling facilities is proposed. The integration problem is formulated to a mixed integer programming model as assignment problem. By using numeric example, the effectiveness of this model is demonstrated. For solving large scale problem, an evolutionary algorithm is developed. Further research will include following:

- Introducing of other search techniques (GA, SA, TS, BB and others)
- Extension of problem definition (division and/or unification of zones, changing of facility capacity)

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Supply Chain Management of Chinese Firms from Institutional View

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Supply Chain Management of Chinese Firms from Institutional View

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[Abstract] Based on survey and statistical analysis, the supply chain management (SCM) of Chinese firms is systematically evaluated from the institutional view. First, an institutional framework for Chinese firms' SCM evaluation is proposed according to the institutional theory and the specific situations of China. Then, focus on the segment of Organizational & Managerial Institution of Firms in the institutional framework, a number of surveys are conducted and analyzed thoroughly. Furthermore, the rough set theory and fuzzy aggregation method are integrated and utilized to compute the weights of the criteria in the questionnaire. Thereof, an index of the Potential Improvement Space (PIS index) is constructed by which the weakness of the current SCM and the improvement opportunities can be identified accordingly. Meanwhile, some insightful conclusions are reached. To name some, 1) In China, the average SCM level of logistics firms lag behind the firms in manufacturing and other industries. 2) Generally, larger firms located in developed areas have higher SCM levels. And the foreign-owned firms do better than private, state-owned or joint venture firms. 3) The 'logistics performance and information technology' is a common weakness for improving the SCM level of Chinese firms.

[Key words] Supply Chain Management (SCM), Chinese Firms, Survey and Statistic Analysis, Rough Set Theory, Fuzzy Aggregation

1 Introduction

In today's global competition environment, facing the rapid technology progress and increasing customer expectations, enterprises find it hard to win the competition only depending on one's own capacity. As a result, the establishment of the supply chain partnership among enterprises and the coordination of the partners are highly valued. The Academic Alliance Forum suggests that the traditional competition of company versus company is changing toward a business model where supply chains compete against supply chains（Robert 2002）. Supply Chain Management (SCM) has become the critical strategic choice for the enterprises to strengthen their competition advantages.

As a fast developing country, China is playing a key role in global economy growth. However, compared with Western firms, SCM of Chinese firms have been lagging behind (Chen, 2003). Maclellan (2003) remarks that China's low labor costs are no substitute for diligent supply chain management. The 2005 Fortune Global Forum held in China suggested that Chinese firms should improve supply chain management to maintain their sustainable and stable development（Wang 2005）. In this circumstance, studies on Chinese SCM are prevailing nowadays. However, most of them are focused on some detail issues such as certain information technologies or mathematical algorithms applications in SCM. Besides these micro-viewpoints, it is quite necessary to get an overall understanding of the SCM level of Chinese firms. In other words, a macro-picture is indispensable for the strategy development and performance improvement of Chinese SCM.

Questionnaire survey is adopted by many scholars in the SCM investigation of Chinese firms. Compared with the wide aspects in SCM, the reported surveys only cover a limited set of facets. Moreover, besides the conventional SCM topics, SCM is influenced by many environmental factors. For example, Chinese government used to control firms directly so that the politics can affect SCM style of Chinese firms seriously. Luk (1998) conceives that the SCM of Chinese firms is influenced by many structural factors, such as inter-provincial and inter-ministerial relationships. Apart from the politics, some other factors such as history and culture also can significantly affect the SCM of Chinese firms. All these considerations construct the institutional environment of SCM of Chinese firms.

This paper dedicates on the SCM evaluation of Chinese firms from the institutional view. Referring to the institutional studies in other fields and considering the specialties of Chinese firms, an institutional framework is proposed and one of its segments, Organizational & Managerial Institution of Firms, is explored by surveying hundreds of Chinese firms. The rest of the paper is organized as follows. In section 2, the previous researches on institutional theory and Chinese firms' SCM are reviewed. Thereof, an institutional framework for Chinese SCM is proposed and explained in section 3. Then, in section 4, focus on Organizational & Managerial Institution of Firms, a survey and its questionnaire is introduced. In section 5, the survey data are statistically analyzed from different viewpoints. In section 6, the rough set theory and the fuzzy aggregation method are integrated and utilized to dig out some quantitative conclusions on SCM performance of Chinese firms. The discussions are given in section 7 and section 8 summarizes the paper.

2 Literature Review

Recently, questionnaire surveys on SCM have been conducting in many Chinese industries. Wang & Chen, etc. (1998, 1999) surveyed the distribution and post-sale services as well as the supply and storage problems. Pyke & Robb, etc. (2000) interviewed 100 manufacturing firms in Shanghai (China) including State-owned, Collectives, or Privately-owned Enterprises. They argued that the difference among these three types of firms were generally insignificant. They also figured that these firms were not as advanced in SCM as

Western firms. Li (2001) surveyed some manufacturing, retail and wholesale firms and concluded that Chinese firms were in their early time of implementing SCM. He (2004) pointed out that most of the Chinese manufacturing enterprises had been aware of the importance of the SCM.

Along with the progress in academic and practical studies, some new aspects emerge in SCM field. The questionnaires used in the former surveys cannot afford to the requirements for the contemporary Chinese firms' systematical SCM evaluation. For example, the survey in Pyke & Robb, etc.(2000) only includes 12 questions and almost all of them deal with the attitude between suppliers and customers. He (2004) designed 18 simple Yes-No questions in his questionnaire. Apparently, the scope is too narrow and the feedback information is too limited to obtain a complete evaluation of the SCM level.

Xu and Ma (2000) conceive that the SCM is influenced by many institutional factors that have not been explored systematically so far. It figures that the credit system is highly correlated with social institutions and playing an important role in cultivating and promoting cooperation between firms. Institutional theory holds that the belief, goals, and actions of individuals and groups are strongly influenced by various environment institutions (Scott, 1987, 1995), and that their role in doing this is subtle but pervasive (Boisot and Child, 1996; Clarke 1991). This theory applies to Chinese SCM and should be studied deeply to comprehending the SCM problems of Chinese firms.

Before employing the institutional theory as the basis to evaluate the SCM of Chinese firms, it is necessary to be clear about the nature of institution. The two commonly used approaches in institutional studies are sociological and economic, which can be complementary to each other (Hirsch and Lounsbury, 1997 Scott, 1992). Sociological institutionalists primarily focus on legitimacy building and role-shaping actions of institutions (Suchman, 1995). Such beliefs and actions can arise out of shared cultural and political systems (Scott, 1992; Zucker, 1987). For economic institutionalists, the relevant institutional framework is a set of political, social, and legal ground rules (North, 1990; Roy, 1997). Based on Dimaggio and Powell (1983, 1991), North (1990), and Selznick (1957), Scott (1995) more finely categorized these formal and informal institutions into regulatory, normative, and cognitive groupings. The most formal are the regulatory institutions representing standards provided by laws and other sanctions. Normative institutions are less formal or codified and define the roles or actions that are expected of individuals. Finally, cognitive institutions represent the most informal, taken-for granted rules, and beliefs that are established among individuals through social interactions among various participants. Although this organizing scheme of institutions is not without controversy (e.g., Hirsch and Lounsbury, 1997), it has been widely used and has proved helpful for analytical purposes.

Institutional theory has been successfully applied in many fields. The US Jet Propulsion Laboratory achieved its space exploration targets of 'faster, better, cheaper' according to a institutional strategy that consist of 'organizational and architectural considerations', 'Process Reengineering', 'a supportive work environment' and 'domestic and international partnership' (Dumas & Walton, 2000). Colombatto (1998) analyzed the Less Developed Country - LDC's failure from an institutional view and highlighted the importance of policy of the LDC countries. Leaptrott (2005) stated that the principles derived from institutional theory could provide efficient insights in understanding the family business.

In the area of SCM, some researchers have already noted the importance of the institutional view. Qing and Cong (2004) summarize some institutional barriers for the development of SCM in Chinese firms including Chinese economic institution barrier， managerial barrier， social credit barrier， practitioners barrier, and non-advanced logistic barrier. Chen (2002) points out that China's logistics system faces three primary institutional limitations, the deficiency of forming system for logistics market demand, the non-specific definition of the logistics business entities, and the disordered market system due to the closed logistics market and inefficient logistics management. Zhou (2002) states that, in China, the development of logistics starve for well law institution.

Although researchers have explored some institutional issues in Chinese SCM, a systematical study on the institutional view of Chinese SCM is still absent. Many researchers prefer to own the less developed SCM or logistics to the institutional problems rather than get an overall analysis of SCM of Chinese firms from institutional view.

3. Institutional framework of SCM of Chinese firms

China's institutional environment is quite different from the Western (Boisot and Child, 1996; Peng, 2000; Peng and Heath, 1996). Here, based on the previous researches and the specific Chinese characteristics, an institutional framework for Chinese SCM evaluation is proposed.

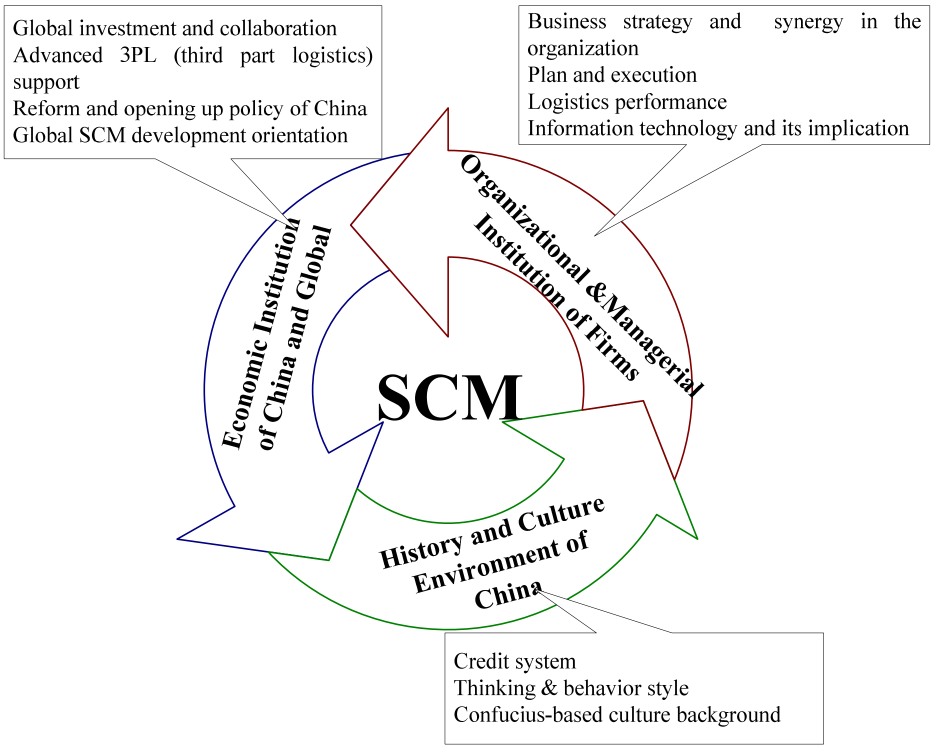

Figure 1 Institutional Framework for Chinese SCM Evaluation

As shown in Fig.1, the institutional framework for Chinese SCM evaluation consists of three segments, Economic Institution of China and Global, History and Culture Environment of China, and Organizational & Managerial Institution of Firms.

In Economic Institution of China and Global, the economic environmental influences of China and global are taken into consideration. On one hand, the global economic affects the supply chain very much (Sullivan & Laurie, 2005). On the other hand, SCM can improve global competitiveness and accelerates the global economic (Krenek & Michael, 1997). In China, to some extension, the government economic policy can determine the direction of the economic development. Before 1980, all Chinese firms must comply with government's administrative plan. From 80s on, reform and opening up policy had boomed Chinese developing speed miraculously.

Economic Institution of China and Global can be separated into four facets. 1) Global investment and collaboration. Global economic actions such as global sourcing and global outsourcing are accepted universally. Industry practitioners have earned huge profit in optimizing the global resources to yield products with lower cost and higher quality. 2) Advanced 3PL (third part logistics) support. 3PL is becoming an effective method and strategy for firms to focus on their core business and improve the efficiency of supply chain operations. 3) Reform and opening up policy of China and many economic policies based on this principle. 4) Global SCM development orientation. Some new trends, such as designed for supply chain, green supply chain, etc., drive the development of SCM and enrich the evaluation of SCM in China.

Another segment in the institutional framework is History and Culture Environment of China. Cognition, which has been proven to be indispensable to the institution grouping, is related to history and culture of one country, especially for China who is famous for its long history and profound culture. For example, although the planned economy has been replaced by the socialism market economy after 1978, the influences of the planned economy still exist so that many firms are still unable to acknowledge the importance of SCM and take action for improvement (Xu, 2004). Chinese culture has many special characteristics. In contrast to the West, Chinese would not share information with anyone they do not have relationships (Goa et al., 1996; Wank, 1996). These characteristics influence the way for Chinese firms to find suppliers or other collaboration partners.

Here, History and Culture Environment of China is separated into three facets. 1) Credit system. Morality is largely derived from the culture and history background. Credit system which belongs to the morality is inevitably influenced by history and culture environment. 2) Thinking and behavior style. The influence of history and culture is too profound to cover in this study. To simplify the framework, many issues are classified into 'thinking and behavior style' such as the approach to provide advice. In USA, advices are directly provided in regular interactions (Fried and Hisrich, 1995). However, in China, providing advices must deal appropriately with the rather formidable culture institution known as 'mianzi'-face or respects. Its relative greater importance in a Chinese-based culture is widely recognized (Bond, 1988). 3) Confucius-based culture background. In a Confucius-based belief system, relatives and educators are considered to be more powerful than government officials in their ability to influence others. Take 'guanxi'-relationship as an example. In USA, relationships between capitalists and their relevant networks of investors, entrepreneurs, and other capitalists are important (Bartlett, 1995), but in China the relationship is even more important. Guanxi acts as an unwritten social rule. It is far more pervasive than economic or legal controls in China. Unlike American and Europeans, Chinese do not rely so heavily on laws, regulations, and contracts. Besides, there is a Chinese philosophy lasting for thousands of years. It is 'Yi He Wei Gui' which means that peace should be put at the priority position. This thought influence the economic activities and the management of Chinese firms profoundly (Wang & Mu, 2006).

The Organizational & Managerial Institution of Firms is another important segment in the institutional framework. It is the most objective segment in the institutional framework concerning the operational considerations for organizations. This segment consists of four sub-segments, 1) Business strategy and collaboration in the organization; 2) Plan and execution; 3) Logistics performance; 4) Information technology and its implementation. The rest of paper will focus on this segment. A questionnaire is introduced and more than two hundreds of firms are surveyed and analyzed thoroughly.

4 Study methodology and sample coverage

4.1 Questionnaire and survey

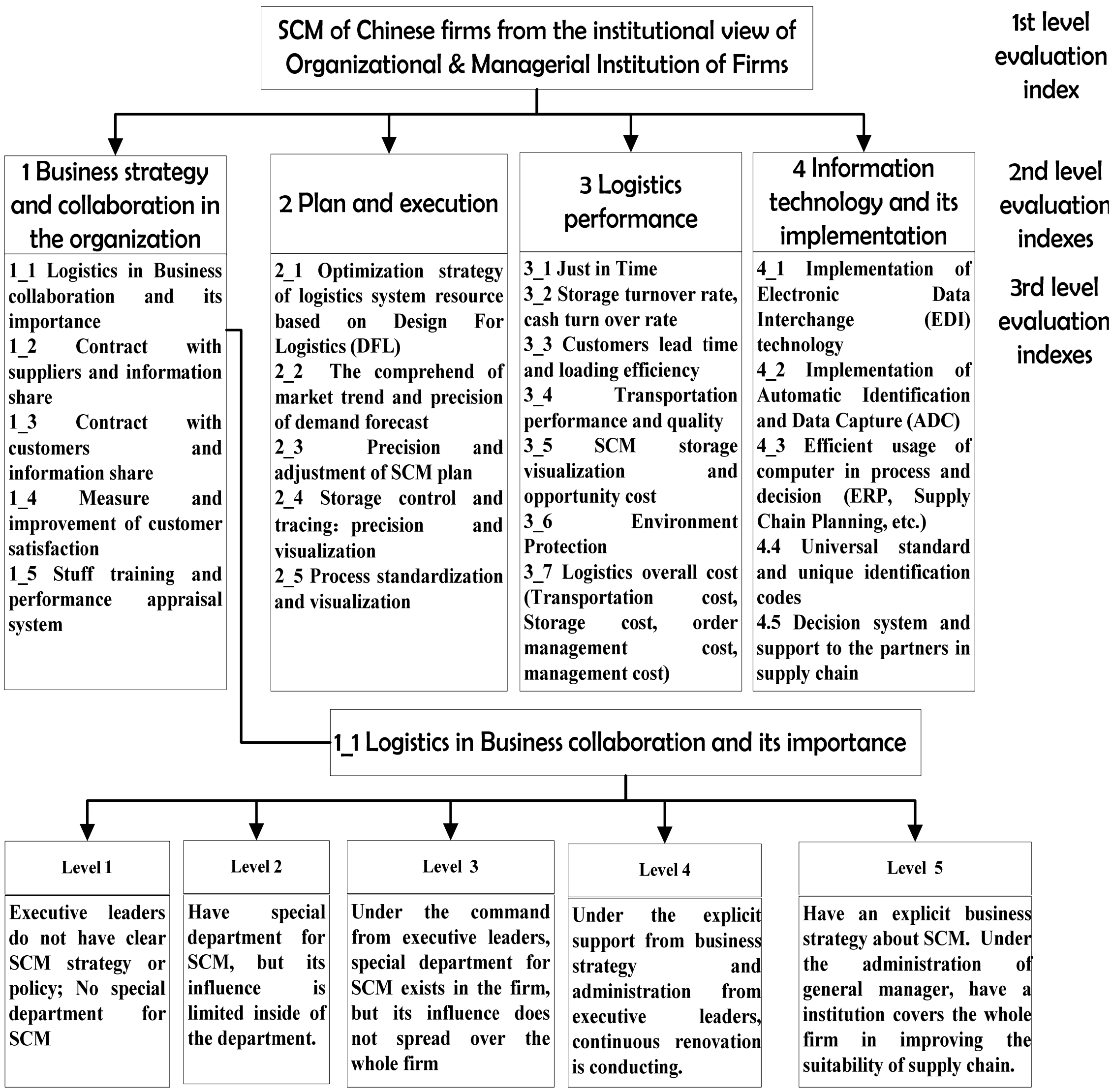

Figure 2 Questionnaire outline

Focusing on segment of the Organizational & Managerial Institution of Firms in the institutional framework illustrated in fig.1, a survey was conducted aiming at evaluating the SCM level of Chinese firms. Corresponding to the four sub-segments shown in fig.1, four categories of questions are designed in the questionnaire and total 22 questions are included. To facilitate the respondents' replying, five levels (marked 1 to 5) and the corresponding detailed descriptions are provided for each question. As an example, the description of the five levels of the question 1.1 is illustrated at bottom of fig.2. The highest score for a firm is 22*5=110. Moreover, an equivalent questionnaire, containing 93 Yes-No questions, was applied in the survey to validate the data so as to guarantee the objectivity and reliability.

4.2 Sample coverage

The questionnaire is sent out to more than 400 firms across China, and 308 firms send back their replies in which 206 are valid. The 206 valid respondents locate across 17 provinces of China and can be classified into three categories as manufacturing industry, logistics industry and others. Fig.3 shows the frequency distribution of each industry in the 206 respondents. Fig.4 shows the location distribution of these firms.

Fig.5 shows the frequency distribution according to the firm annual turnover (small, middle-size, large and mega). Referring to the definition of 'Small and Middle-size Enterprises Promotion Law' in China, the annual turnover (in million RMB) of these four groups are [0,2), [2, 13), [13, 132) and [132, ∞) respectively.

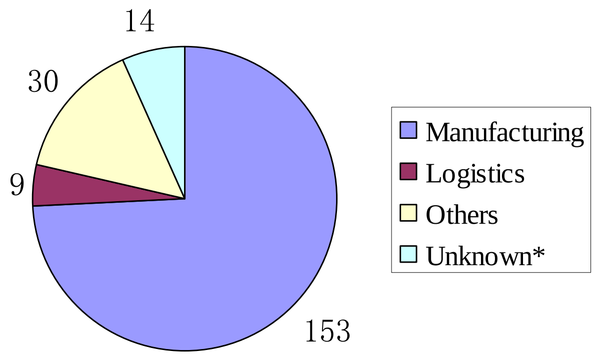

Figure 3 Number distribution of firms in each industry

（* Unknown means the related information is missing）

Figure 4 Location distributions of firms

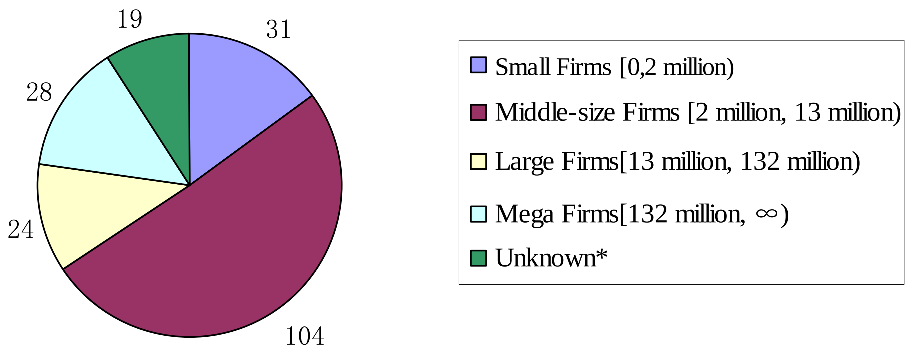

Figure 5 Size distribution of firms

（* Unknown means the related information is missing）

5 Primary analysis results

First of all, the basic statistical analysis is conducted to test if the SCM levels are distinct between different industrial firms with different locations, sizes, and ownerships.

5.1 Firms with different industries

Fig.6 shows the average scores of the three industries in the four questionnaire categories. Figures 7 to 10 give more detailed evaluation for each index in the four categories.

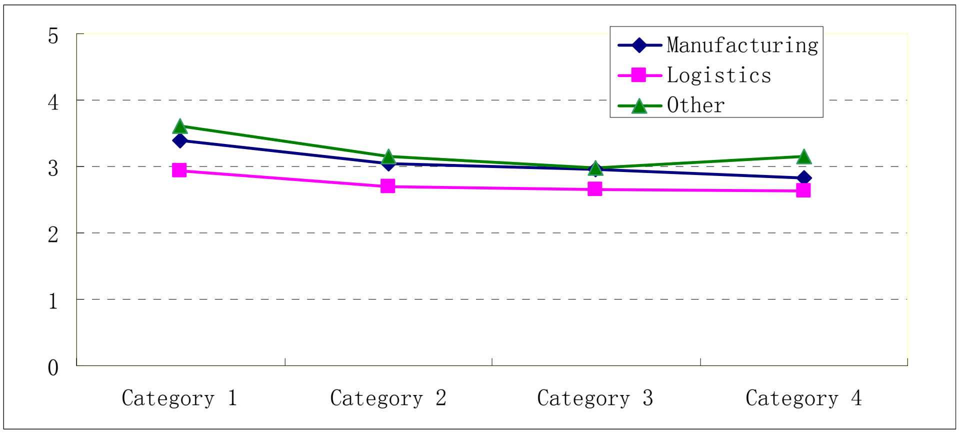

Figure 6 The average scores of the four categories

The three different colored lines represent three different industries. As one can see in fig.6, the three lines have the similar pattern that firms of every industry have the highest average score in category 1 and comparatively lower averages in categories 3 and 4. It implies that the firms have already known the strategic importance of the SCM, but they have not pay enough attentions on the logistics performance and the applications of information technology. Among the three industries, SCM scores of manufacturing industry and others are similar, but logistics industry has the lowest scores with an average gap of 0.5 point.

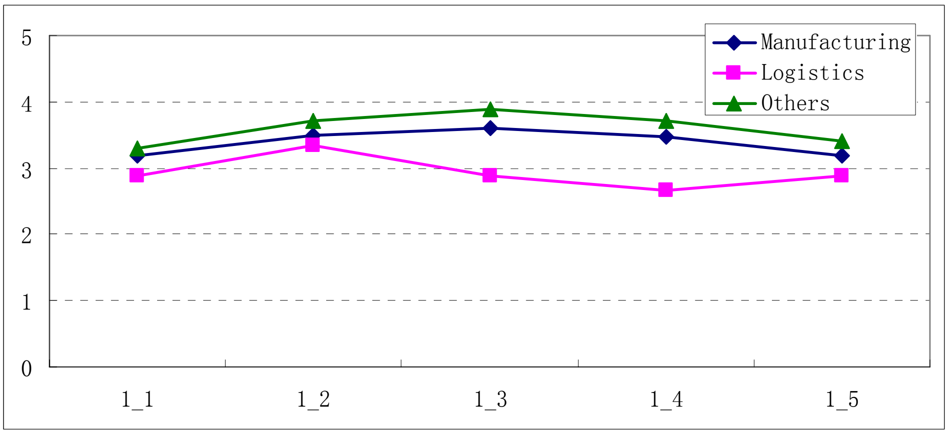

Figure 7 The average scores of indexes in category 1

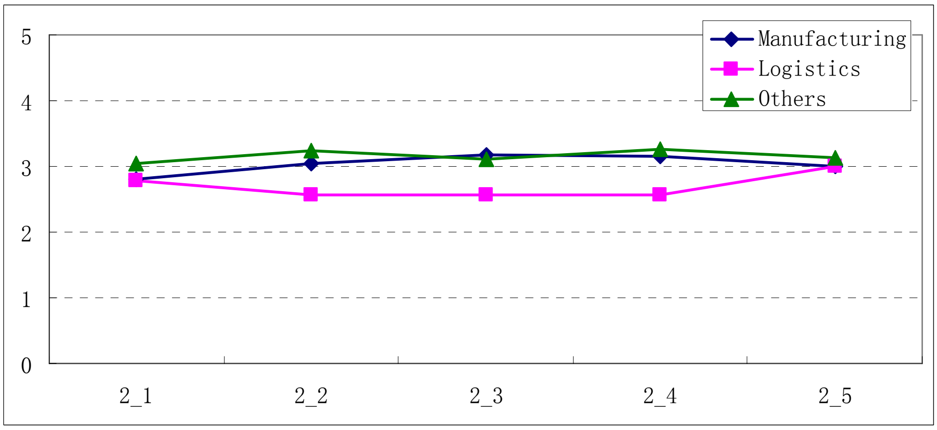

Figure 8 The average scores of indexes in category 2

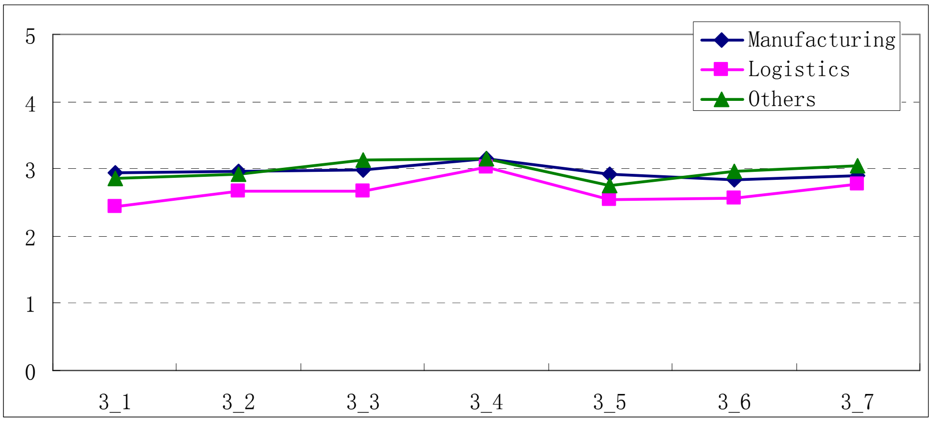

Figure 9 The average scores of indexes in category 3

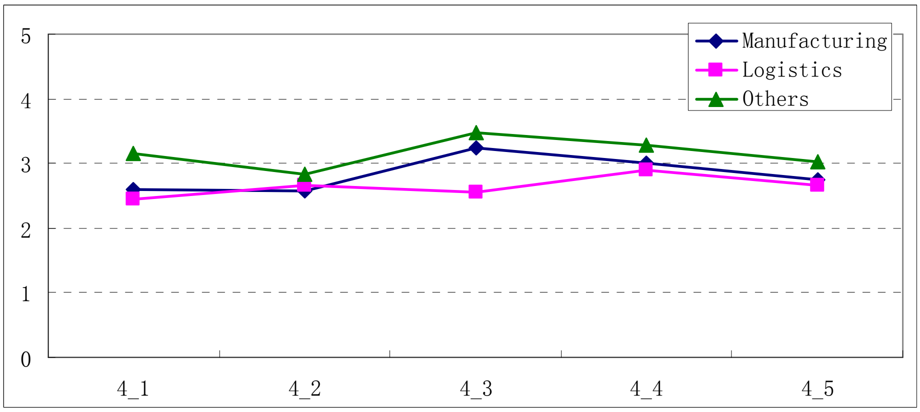

Figure 10 The average scores of indexes in category 4

Taking a closer look on fig.7, one can see that the index 1_3 (Contract with customers and information share) has the highest score close to 4 point. Referring to the questionnaire, the description of 4 point is that “Company has signed formal written contract with almost all customers. And a method has been constructed to facilitate customer-oriented information sharing and achieve win-win scheme.”

As the logistics is a relatively new industry in China (the first logistics firm appeared in 1999), although logistics firms increase exponentially, they are still in a low SCM level. Among all the 22 indexes, in 1_3 (Contract with customers and information share) and 1_4 (Measure and improvement of customer satisfaction), logistics industry firms has the most significant distance from manufacturing industry and others. It suggests that logistics industry firms are not doing well in customer service. Discrepancy is also obvious in the indexes of 2_2 (The comprehend of market trend and precision of demand forecast), 2_3 (Precision and adjustment of SCM plan), 2_4 (Storage control and tracing： precision and visualization) and 4_3 (Efficient usage of computer in process and decision (ERP, Supply Chain Planning, etc.)).

5.2 Firms with different locations

Our survey covers many provinces located in seven different areas of China. Figure 11 shows the average SCM scores from highest to the lowest of firms located in the seven different areas.

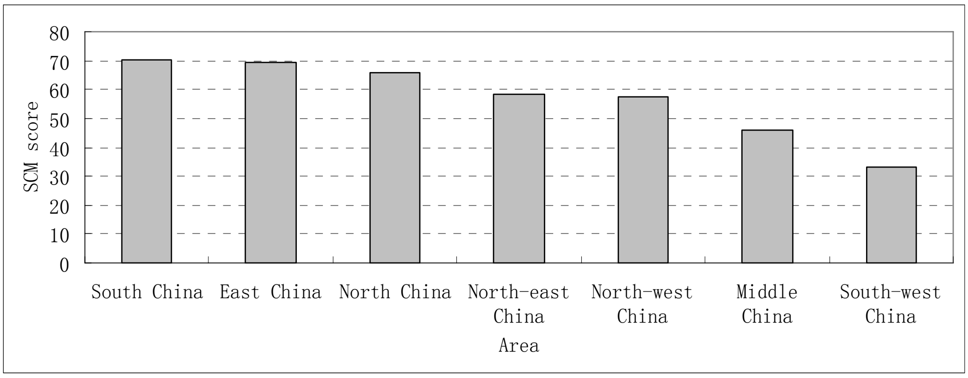

Figure 11 SCM scores for firms in different areas

T-test shows that the SCM level of firms in undeveloped areas of North-west, Middle and South-west China is significantly lower than that of firms in developed areas of South or East China at a 95% confidence level. We can confidently say that firms in more developed areas of China have higher SCM level.

5.3 Firms with different sizes

For the dimension of size, the 206 respondent firms can be divided into four groups as small, middle-size, large and mega. Fig.12 shows that firms with larger annual turnover usually have a high SCM level. Especially for mega firms whose annual turnover is over 132 million RMB, their average SCM level is significantly higher than the firms of smaller sizes at a 99% confidence level. Therefore, small and middle-size firms need to strengthen their SCM in competition with large and mega firms.

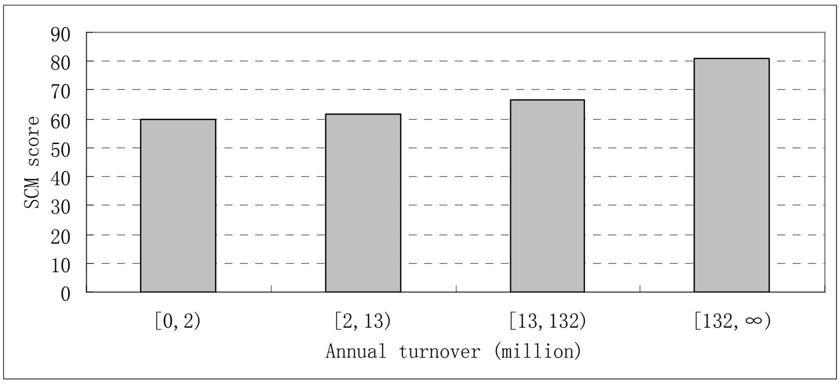

Figure 12 Average scores on SCM for firms with different size

5. 4 Firms with different ownerships

In China, state-owned firms are established and maintained by the government. Conversely, private firms had been suppressing for a long period of time in China. Along with implementation of the Reform and Open Up Policy, the private firms are booming and more and more foreign investments are permitted to enter China.

Fig.13 shows the average SCM scores for the four kinds of ownerships as foreign-owned firm, state-owned firm, joint venture firm and private firm respectively. T-test shows that the SCM level of foreign-owned firm is remarkably higher than that of other three kinds of ownership at a 99% confidence level. In addition, the average SCM score of State-owned firms is relatively high with a considerably large standard deviation of 19.73. Foreign-owned firms have the smallest standard variance of 14.62.

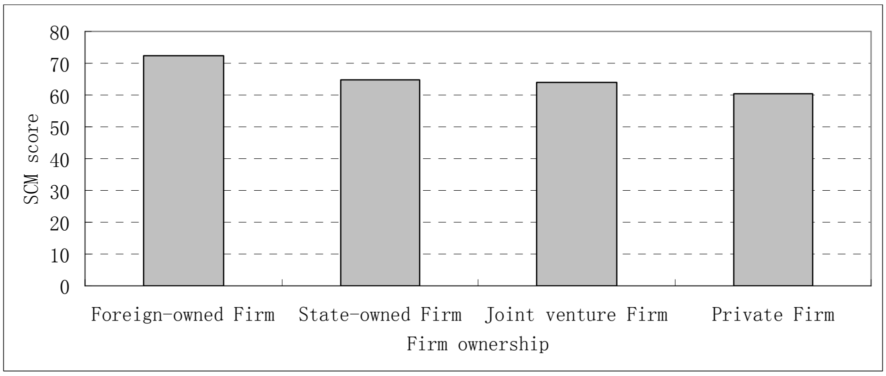

Figure13 SCM score for firms with different ownership

6 Further analyses

In this survey, totally 22 indexes are employed to measure the SCM level, the higher the better. However, it’s unrealistic for a certain firm to improve all the 22 indexes synchronously given limited resources. Therefore, it is necessary to weight the 22 indexes quantitatively so as to assist the firm to establish its customized SCM-improvement strategy.

6.1 RST & FA integrated method

The prevalent approach for the weight allocation, such as Analytic Hierarchy Process (AHP), depends mainly on the subjective experience of the experts. Here, integrating the rough set theory (RST) and fuzzy aggregation (FA) method, the weights of the indexes are derived objectively from the survey data.

Rough set theory (RST) is a fairly new mathematical theory developed in recent years which has the ability to deal with imprecise, uncertain, and vague information. It can find valid and potentially useful knowledge in data. Since RST was put forward by Pawlak（1982）, it has become increasingly popular and has been successfully applied in such fields as machine learning, data mining, and intelligent data analyzing (Yu 2002) .

In RST, an information system with decision attribute can be conveniently represented by a kind of decision table. In our survey, there is no decision attribute which shows clearly the SCM level of firm such as “Excellent”, “Good”, “Average” or “Bad”. So, we can not classify the cases by given information. By Pawlak (1991), knowledge can be seen as the ability to perform classifications. The weight of an attribute can be obtained by compare the different classifications before and after this attribute is removed. Therefore, the fuzzy aggregation (FA) is used to classify the cases set U and the subset C_t with an attribute $\{a_t\}$ is removed ($C_t=U-\{a_t\}$). Meanwhile, the information entropy is employed to quantitatively evaluate the change of the knowledge imply in the classifications. Information entropy is broadly used to measure the uncertainty of rough set prediction. Miao and Wang (1997) used information entropy in defining the corresponding entropy in the rough set theory and proved some basic theorems.

Let $A=\{X_1,X_2,\cdots X_n\}$ be the partition of U after fuzzy aggregation, the information entropy of A is called initial entropy

$$H(A)=-\sum_{i=1}^{a} p(X_i)\bullet\log_2(p(X_i)) \qquad (1)$$

Where, $P(X_i)=\dfrac{card\ X_i}{card\ U}, i=1,2,\cdots,n$.

Let $B_t=\{Y_1,Y_2,\cdots,Y_m\}$ be the partition of C_t, the condition entropy of *A* given B_t is

$$H_{\lambda_k}(A|B_t)=-\sum_{i=1}^{m}P(Y_i)\sum_{j=1}^{n}P(X_j|Y_i)\log_2 P(X_j|Y_i) \qquad (2)$$

Where $P(X_j|Y_i)=\dfrac{card\ (X_j\cap Y_i)}{card\ Y_i}, i=1,2,\cdots m;\ j=1,2,\cdots n$;

and $P(Y_i)=\dfrac{card\ Y_i}{card\ U}, i=1,2,\cdots,m$.

Huang (2003) used the following equation to evaluate the information loss after an attribute is removed from the universal set.

$$M_t'=\sum_{k=1}^{p}\lambda_k\frac{1}{I_{\lambda_k}(A,B_t)} \qquad (3)$$

Where, $I_{\lambda_k}(A,B_t)=H_{\lambda_k}(A)-H_{\lambda_k}(A|B_t)$. $I_{\lambda_k}(A,B_t)$ is called the mutual information between *A* and B_t under the given threshold λ_k. It reveals the information could be obtained by *A* from B_t. The bigger $I_{\lambda_k}(A,B_t)$, the more information *A* could obtain from B_t, the less important the deleted attribute.

However, Huang oversimplify the problem. Some information loss may turn out to be infinite using equation (3) because the value of $I_{\lambda_k}(A,B_t)$ may be 0 due to the unreasonable threshold λ_k. The minor differences between the obtained fuzzy similarity relation matrixes are very likely to be ignored in classification under a big threshold. For an extreme example, if λ_k =1, all classifications would be the same as an identity matrix.

According to the information theory, $H(A|B_t)$ represents the remained uncertainty in *A* under the given knowledge B_t. The more uncertainty remains the less significant of B_t for *A*. Since the remained uncertainty is caused by the remove of the attribute $\{a_t\}$, we can evaluate the information loss of removing $\{a_t\}$ as follows.

$$M_t = \sum_{k=1}^{p} \lambda_k H_{\lambda_k}\left(A \middle| B_t\right) \tag{4}$$

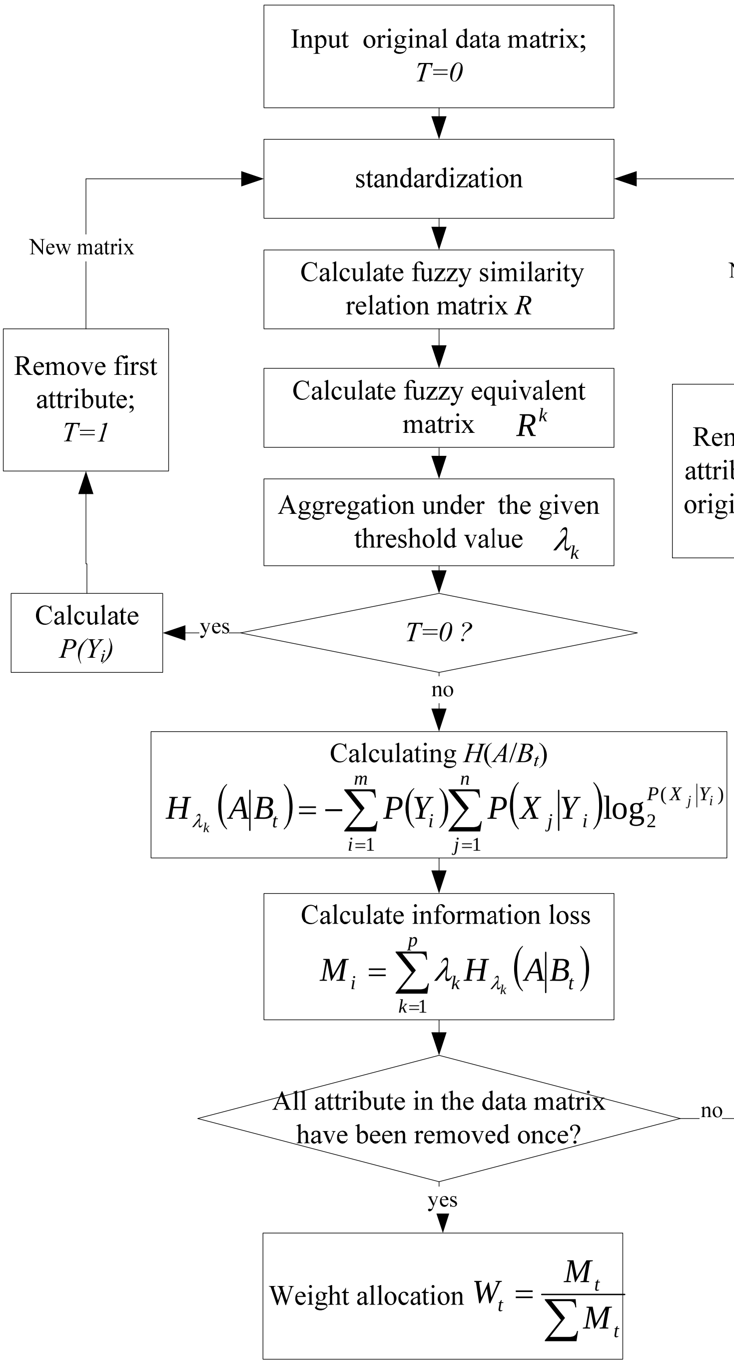

Figure 14　Weight allocation applying RST&FA

Using equation (4), the unreasonable result (infinite information loss) of equation (3) could be avoided. It's obviously that the change tendency of M_t in equation (4) is the same as M_t' in equation (3). Weights of the attributes could be allocated according to the corresponding information loss when the corresponding attribute in the universal set has been removed. Then the weights can be standardized as follows.

$$W_t = \frac{M_t}{\sum M_t} \qquad (5)$$

The flowchart of the weight allocation algorithm applying RST&FA is shown in fig.14.

6.2 Weight allocation

As shown in fig.2, the questionnaire in our survey is a kind of 3-level hierarchical structure. The RST&FA calculation is first conducted within different categories (the 3rd level in fig.2). Therefore, the scores of categories (the 2nd level attributes) could be calculated by

$$S_i = \sum_{j=1}^{n_i} w_{ij}' S_{ij} \qquad (6)$$

Where S_i represents the score of the category i; w_{ij}' is the internal weight of index j within category i that derived in RST&FA calculation; S_{ij} is the score of the index j in category i. n_i represents the number of indexes in category i. After the scores of the total 4 categories are obtained, repeat the process showed in fig.14 to allocate the weights of the 2nd level attributes. Then, the weights of the 22 indexes could be obtained by

$$w_{ij} = w_i \bullet w_{ij}' \qquad (7)$$

Where w_{ij} represents the weight of index j in category i; w_i represents the weight of category i; w_{ij}' is the internal weight of index j within category i.

6.3 Result analysis

Table 1 is the weights allocation result using the theory described above.

Table 1 Weights allocation result

The 2nd level attribute	Weight	The 3rd level attribute	Weight

1. Business strategy and collaboration in the organization	0.1957	1_1 Logistics in Business collaboration and its importance	0.0372
		1_2 Contract with suppliers and information share	0.0419
		1_3 Contract with customers and information share	0.0451
		1_4 Measure and improvement of customer satisfaction	0.0305
		1_5 Stuff training and performance appraisal system.	0.0410
2 Plan and execution	0.1607	2_1 Optimization strategy of logistics system resource based on Design For Logistics (DFL)	0.0313
		2_2 The comprehend of market trend and precision of demand forecast	0.0360
		2_3 Precision and adjustment of SCM plan	0.0266
		2_4 Storage control and tracing：precision and visualization	0.0382
		2_5 Process standardization and visualization	0.0287
3 Logistics performance	0.3218	3_1 Just in Time	0.0626
		3_2 Storage turnover rate, cash turn over rate	0.0386
		3_3 Customers lead time and loading efficiency	0.0436
		3_4 Transportation performance and quality	0.0427
		3_5 SCM storage visualization and opportunity cost	0.0507
		3_6 Environment Protection	0.0450
		3_7 Logistics overall cost (Transportation cost, Storage cost, order management cost, management cost)	0.0386
4 Information technology and its implementation	0.3218	4_1 Implementation of Electronic Data Interchange (EDI) technology	0.0592
		4_2 Implementation of Automatic Identification and Data Capture (ADC)	0.0734
		4_3 Efficient usage of computer in process and decision (ERP, Supply Chain Planning, etc.)	0.0536
		4.4 Universal standard and unique identification codes	0.0722
		4.5 Decision system and support to the partners in supply chain	0.0633

According to the survey data and weights in table1, the weak points of the Chinese SCM for different industries could be derived as shown in figures 15-17. The x-coordination is the weight of every index. The y-coordination is the average score of the index. The plane is divided into four quadrants by two lines of x = 0.05 (≈1/22) and y = 3.0. The points located in the fourth quadrant could be regarded as the weak point because such points represent the indexes with relatively higher weights and lower scores. The weak points should be paid more attentions.

The figures15, 16, 17 testify that the logistics industry has the lowest SCM level compared with manufacturing and other industries. Since in fig.16, most of the points are below the horizontal line and much more points locate in the fourth quadrant.

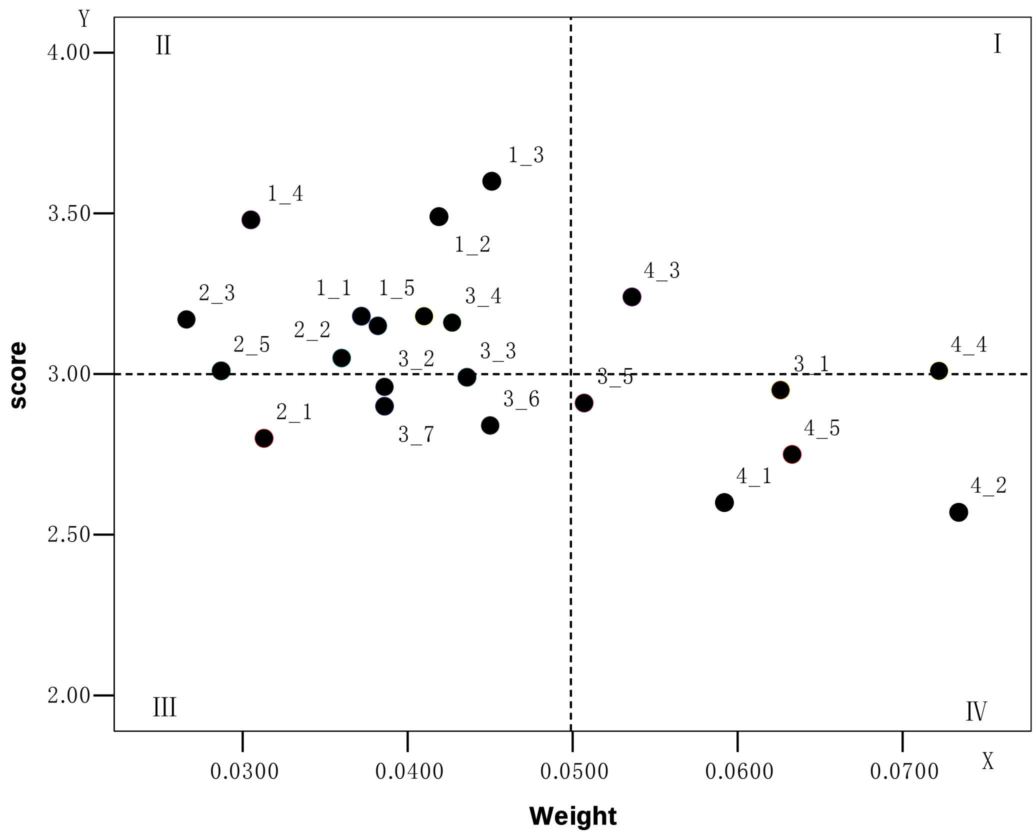

Figure 15 Weak points of the manufacturing firms

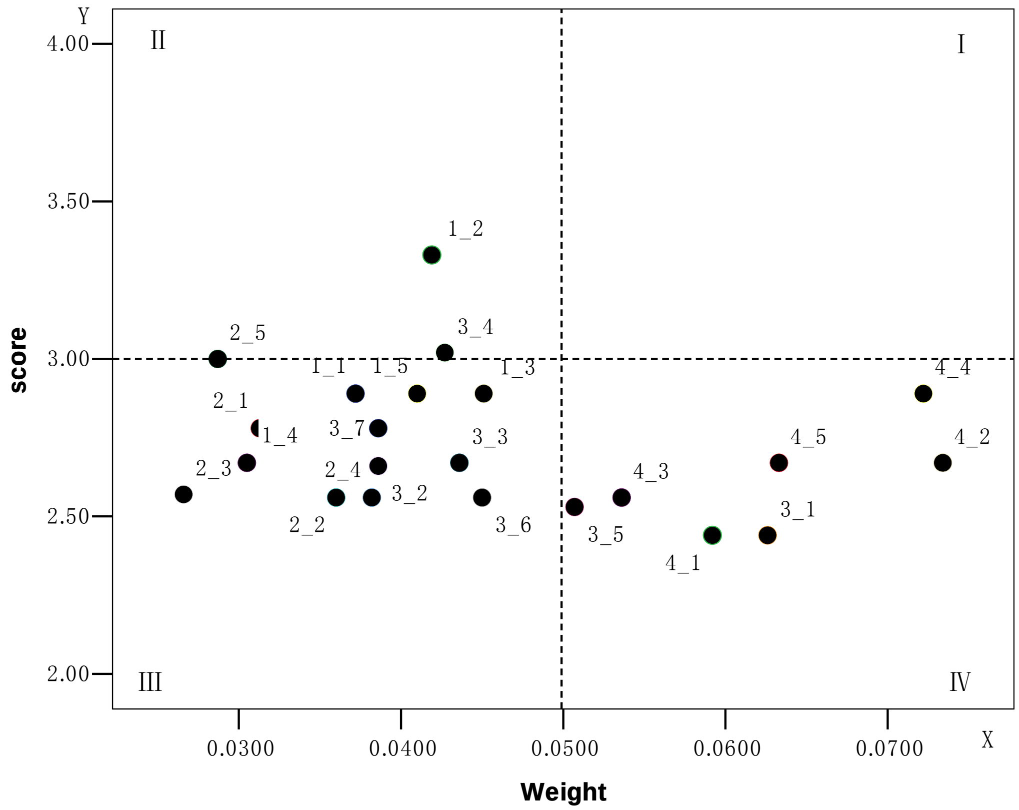

Figure16 Weak points of the logistics firms

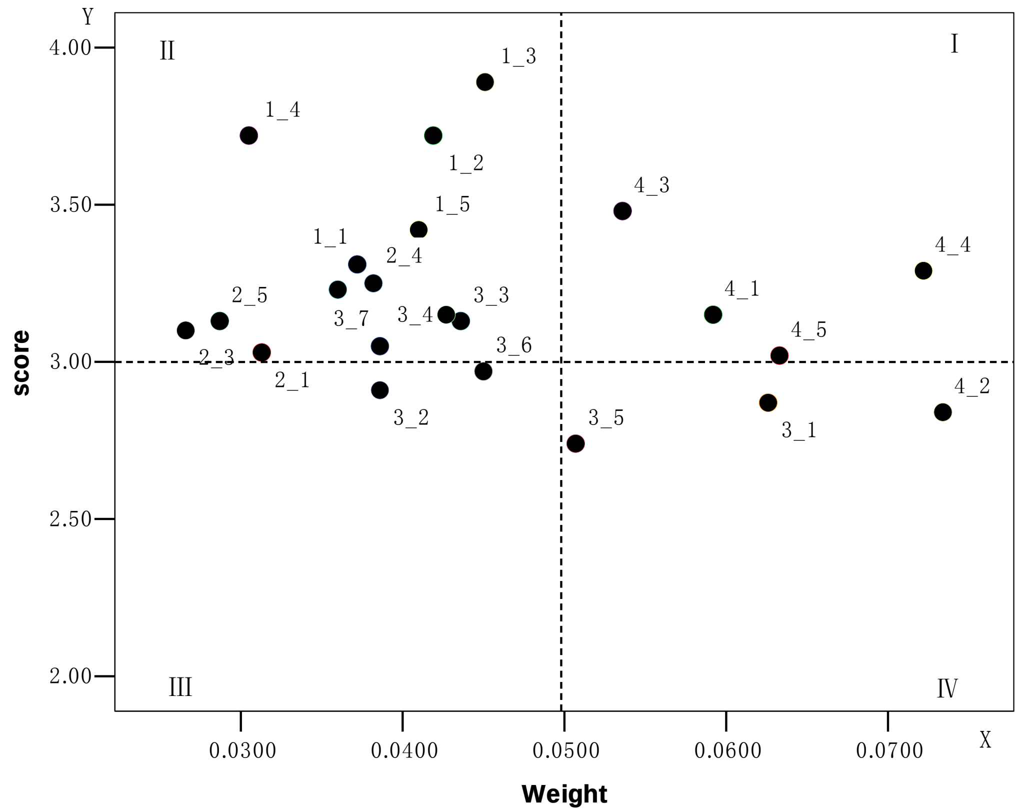

Figure 17 Weak points of the other firms

6.4 For a certain firm

Besides the weakness analysis of different industries, we still need to establish a customized improvement strategy for a specific firm according to its features. To this end, an index of potential improvement space (PIS index) is proposed to assist the firm to find out the most promising improvement facets.

The PIS index is defined as,

$$PIS = (5 - S_i) \times W_i \qquad (8)$$

Where 5 is the maximum score of the index; S_i is the score of the firm in index i; W_i is the weight of index i.

For instance, the 181st case is chosen as an example to illustrate the application of PIS. The score of the firm and the PIS is shown in table 2.

Table 2 The PIS of the example firm

Index	1_1	1_2	1_3	1_4	1_5	2_1	2_2	2_3	2_4	2_5	3_1
weight	0.037	0.04	0.045	0.0305	0.041	0.03	0.036	0.027	0.0382	0.0287	0.0626
score	5	5	5	5	5	1	4	4	5	5	4
PIS	0	0	0	0	0	0.13	0.036	0.027	0	0	0.0626

Table 2 The PIS of the example firm (cont.)

Index	3_2	3_3	3_4	3_5	3_6	3_7	4_1	4_2	4_3	4_4	4_5
weight	0.039	0.04	0.043	0.0507	0.045	0.04	0.0592	0.073	0.0536	0.0722	0.0633
score	5	3	5	4	5	5	1	1	1	5	1
PIS	0	0.09	0	0.0507	0	0	0.2368	0.294	0.2144	0	0.2532

Based on table2, the Pareto chart is derived as in fig.18. One can see that among 22 indexes, 4 indexes (4_2, 4_5, 4_1, 4_3) in the 4th category occupy about 71% of the whole PIS. So, for the example firm, the most effective measure to improve its SCM level should be the implementation of information system (category 4 in questionnaire). More specific, the application of the ADC (Automatic Identification and Data Capture) technology (index 4.2) should be the first priority.

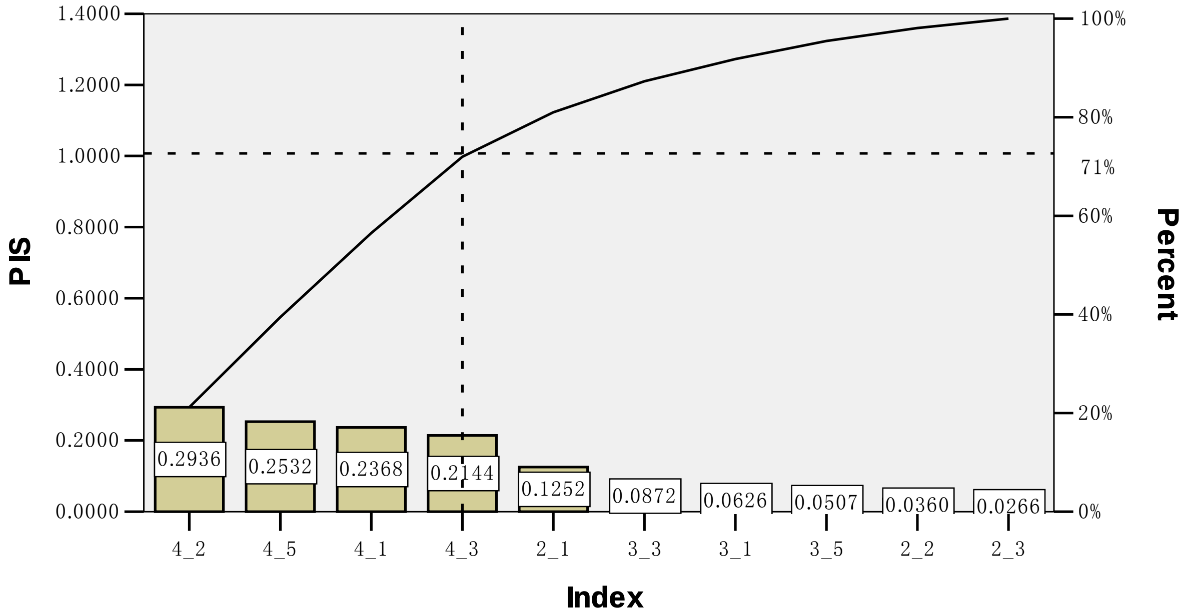

Figure 18 Pareto Chart of the example firm

7 Discussions

7.1 Chinese logistic industry

In this paper, both section 5 and section 6 demonstrate that the SCM level of the logistic industry in China is significantly behind the manufacture and other industries. According to the above analysis, the following clues can be reached,

(1) Deficient understanding of logistic

In fig.6, the score of logistic industry has significant distance from manufacture industry in category 1—business strategy and collaboration in the organization, especially in index 1_3 (Contract with customers and information share) and index 1_4 (Measure and improvement of customer satisfaction). The low score of the logistic industry is caused by the conventional neglecting of the customer service. In the planned economic time (before 1978), Chinese government played the key role in scheduling and managing the material flow, firms were used to put their emphasis on manufacturing other than logistics. Meanwhile, started from 1999, the logistic firms only exist for several years in China. In many Chinese logistic firms, the understanding of the logistic is usually confined in a narrow area such as transportation, storage, etc. (Chen, 2002) .

(2) Lack of professions

The most significant discrepancy that the logistic industry left behind lies in category 2—plan and execution. In category 2, the discrepancy is very obvious in the 2_2 (The comprehend of market trend and precision of demand forecast), 2_3 (Precision and adjustment of SCM plan), 2_4 (Storage control and tracing： precision and visualization). The lack of specialists should be responsible for the low score of the logistic industry in these indexes. Predicted by Yan (2005), China lacks about 500,000 logistic professions. According to a report of CAWS (China Association of Warehouses and Storage (http://www.cwl.org.cn/)), the average age of the warehouseman in China is over 48. Those aged people who usually don’t well educated are incapable in the modern supply chain management.

(3) Inefficient use of information technology

Another reason that the logistic industry left behind is the unsatisfied applications of the information technology. In figure 10, the score of logistic in index 4_3 (Efficient usage of computer in process and decision (ERP, Supply Chain Planning, etc.)) is substantially lower than that of manufacturing industry. It shows that the logistic firms in China tend to neglect the importance of information technology while the IT systems, such as ERP, SCM, etc., are becoming prevailing in Chinese manufacture sector.

7.2 The questionnaire analysis

The design of the questionnaire is the foundation of the survey and the subsequent analysis. To explore the structural rationale of the questionnaire, it is studied using the factor analysis method.

Table 3 Rotated component matrix and classification of indexes

	Component				
	1	2	3	4	5
Index1_1	.321	.214	.545	.294	.277
Index1_2	.251	.200	.679	.224	.256
Index1_3	.156	.148	.790	.204	.001
Index1_4	.259	.162	.517	.448	.342
Index1_5	.210	.292	.313	.569	.288
Index2_1	.518	.516	.318	.111	.074
Index2_2	.232	.287	.246	.678	.194
Index2_3	.410	.203	.261	.668	.023
Index2_4	.485	.221	.416	.471	.026
Index2_5	.426	.340	.374	.425	.221
Index3_1	.539	.379	.154	.324	.259
Index3_2	.663	.269	.098	.398	.146
Index3_3	.742	.104	.220	.146	.153
Index3_4	.593	.092	.242	.355	.395
Index3_5	.605	.348	.241	.226	.142
Index3_6	.306	.209	.191	.181	.795
Index3_7	.602	.367	.308	.241	.183
Index4_1	.127	.744	.098	.359	.116
Index4_2	.125	.734	.007	.285	.386
Index4_3	.326	.606	.417	.192	-.121
Index4_4	.402	.573	.411	.148	.135
Index4_5	.395	.626	.400	.032	.121

The analysis shows that five factors can obtain about 70% in cumulative rotation sums of squared loadings. Meanwhile, the Barlett's test demonstrates that the data of this survey is suitable for the factor analysis because its KMO is 0.962 and sig.=0.000. And the 22 indexes should be classified into five categories as shown in Table 3.

On the whole, the design of the categories in the questionnaire is proper except the indexes 1_5, 2_1, 3_6. Based on the factor analysis, it seems more suitable to put index 1_5 (Stuff training and performance appraisal system) into category 2 (Plan and execution). As for index 2_1 (Optimization strategy of logistics system resource based on Design for Logistics), it seems more closely related with the indexes in category 3 (Logistics performance). The index 3_6 (Environment Protection) is obviously an exception with a high value of 0.795. This phenomenon suggests us to take the index 3_6 out of the survey. To the author's opinion, "environment protection" is something related to the latest concept of the Green Supply Chain Management. Referring to the institutional framework (see fig.1), it could be put into ‘Global SCM development orientation’ in the segment of the ‘Economic Institution of China and Global’.

8 Conclusions

In this paper, the supply chain management of Chinese firms is explored systematically from the institutional view. To facilitate the analysis, an institutional framework for Chinese SCM evaluation is proposed. Three segments, e.g., Economic Institution of China and Global, History and Culture Environment of China, and Organizational & Managerial Institution of Firm are integrated in this framework. Focus on the segment of Organizational & Managerial Institution of Firm, a survey is carried out and the data are studied thoroughly and some insightful conclusions are reached.

1) The SCM level of the logistics industry is lower than that of the manufacturing and other industries. In addition, foreign-owned firms or firms in costal developed areas or with larger scale have better SCM performance than that of other firms.

2) The weights of the 22 indexes are allocated quantitatively and the weak points of different industries are distinguished. Moreover, the PIS (Potential Improvement Space) index is proposed as a reference for a specific firm to customize its own SCM improvement strategy.

3) The factor analysis on the questionnaire shows that the design of the categories and indexes in the questionnaire is reasonable except the indexes of 1_5, 2_1, and 3_6.

Although the institutional framework and the corresponding analysis proposed in this paper provide a reference schema in exploring the institutional related issues of Chinese SCM, some important problems are still left for the future study. For instance, the usefulness of the PIS index should be verified by re-survey the case firm and testified by conducting some corresponding improvement actions. Meanwhile, the structure of the questionnaires and the methods in allocating weights should be refined to get a more precise evaluation. In addition, the questionnaires that cover the other two segments in the institutional framework should be designed and integrated to give a whole picture of the Chinese SCM levels from institutional view.

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Conceptualising a macro-institutional perspective of the environment-strategy-performance relationship in supply chains

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ABSTRACT

Supply chain management is a practitioner-generated discipline, which has gained much popularity in the last two decades. Adopting a supply chain perspective also involves the address of structural decision criteria relating to capacity, size and location of supply chain activity, the ‘supply chain’ typified by a network of independent firms. As a result, it becomes important to address globalisation and geographic aspects, inherent especially in any supply chain perspective, an area that is scarcely dealt within supply chain management literature. The importance of supply chain activity adjusting to its broader institutional context, such as the “geovalent” aspect of business processes, is therefore reemphasised.

This paper conceptualises a macro-institutional perspective on supply chains, thereby establishing a solid theoretical foundation for adopting an institutional view of SCM. The approach employed is an integration of theoretical paradigms, on how macro institutions are reckoned with when analysing *environmental complexity* affecting organisations, in International Business (IB) and Operations Management/Strategy (OM) literature. The conceptual framework is then translated to a decision-making problem (model) at the managerial level, using an Analytic Hierarchy Process (AHP) approach, which demonstrates the use of the macro-institutional perspective in action.

INTRODUCTION

Starting point of considerations

Supply chains are interesting research objects as there are many facets that can be studied, either the actors such as manufacturers, suppliers and customers or flows such as flows of goods and related information. The very context of a supply chain, in fact, initiates added complexity both in terms of the content and process in decision-making. Following Schneeweiß (2003) we can also investigate the process of partially autonomous decision making, where the supply chain actors are involved in a distributed decision making situation. The decision making process can be differentiated into strategic, tactical and operational decisions, typically for and between a supplier and a producer. As different actors inside and outside the involved actors with different information background are involved, information asymmetry is the consequence.

Stratton and Warburton (2006) discuss how to manage trade-offs in global supply chains and ask how internal and external system variation and uncertainty have an impact on a supply chain. Internal and external can thereby be seen as within and outside of a firm which is embedded in a network of suppliers and customers. Handfield and Nichols (1999) state thereby that organisations today believe that it is no longer sufficient to manage their own organisations and that they must also be involved in the management of the network of all upstream firms that provide inputs (directly or indirectly), as well as the network of downstream firms. The network of supply chain would include “all activities associated with the flow and transformation of goods from the raw materials stage (extraction) through to the end user, as well as the associated information flows” (Handfield and Nichols, 1999). The institutions which are involved in this network are companies which make this connection successful. Mentzer et al. (2001) refer here to different levels of network involvement ranging from a direct supply chain which is based on three companies up to the ultimate supply chain which include all companies. Accordingly, a new belief is that companies will no longer compete against companies, but rather supply chains will compete against supply chains (Academic Alliance Forum, 1999; Fawcett and Clinton, 1997; Monzcka and Morgan, 1997 and Vokurka et al., 2002).

An interesting twist comes into play as firms increasingly participate in cross-border interrelationships not only with other firms as in a traditional supply chain setting, but also with particular national environments like countries and regions, thereby expanding the scope of supply chains and inter-organisational settings. A prominent example is provided by Caroll (2004) who presents the efforts of India for becoming a major sourcing partner for Wal-Mart. From our viewpoint, this represents a structurally complex supply chain scenario. Looking at the example of India as a main supplier for Wal-Mart (see Caroll 2004), we see that supply chain relations and the management of their performance are getting more complex. For Wal-Mart, the question would be – how to select countries that offer a ‘supplier-friendly’ and ‘consumer-friendly’ environment. For countries, the question would be, what infrastructure to provide in order to have the companies located in that country to achieve the best supply chain performance possible. And in this instance, supply chain decision-making represents a “site location” and “resource allocation” problem at a strategic level (see Badri, 1999). From this point of view, Rabelo et al. (2006), Yuriomoto and Masui (1995) or Badri (1999) can be seen as prominent examples that include in their analysis some macro dimensions such as political stability, infrastructure or governmental restrictions.

German logistics literature distinguishes thereby between different institutional levels such as macro-, micro- and meta/meso-logistics systems. Macro-logistics is the primary system that provides the necessary infrastructure for logistics systems. Micro-logistics though refers to all logistics problems on a company level while meta/meso-logistics refers to logistic partnerships of companies. Most of the literature deals with micro-/and or meta/meso- institutions which means that the research objects are either flows between supply chain actors or problems that are solved on a company level (see e.g. Pfohl, 2004 or Ihde, 2001).

Yet from a supply chain management perspective, we are still faced with a situation where there is no unifying theory or literature stream, which deals exclusively with the issue of macro level institutional constraints that impede or facilitate better supply chain management at the firm (micro) or supply chain (meso) levels (Banomyong, 2006). For example, the understanding of the institution in Schneeweiß (2003) is that of a company, which we consider as being on a micro-logistics level.

As a starting point, it becomes important to recognise what the notion of institution implies. Following the ideas of North (1990, 1992 and 1994), we understand institutions as the rules of a game in which organizations, as groups of individuals are bound by some common purpose in order to achieve certain objectives, are embedded. In this paper, we seek to further develop the notion of and analyse the macro institutions surrounding supply chains and their operations. This we term as assuming a macro-institutional perspective on supply chains. As is evident from the literature reviews performed in this paper, such a perspective differs from the one most commonly used in the supply chain domain, which has a larger focus on the supply chain actors, relationships and consequences in terms of specific supply chain management problems. A macro institution, as shall be clear further on, is to be understood as that super setting, which embeds micro supply chain systems, and provides the indispensable environment needed to generate performance.

The underlying problem

Our underlying problem originates in a hypothetical context, whereby a supply chain manager is considering outsourcing a large part of the organisation's production to a low wage country. The product in question is functional in nature, in its maturity stage and faces stable demand. However, since the product is readily manufactured in all four low wage countries and does not require skill-intensive technologies, the problem of selecting the best supplier actually focuses around selecting the most "reliable" source, in a market that competes on delivery reliability and low price. However, faced by excessive pressure from the top-management to explore cheaper sources of production and other environmentally munificent factors readily available in low wage countries, the manager has to select alternative solutions based on other constraints that each of the four locations offer, and there exist possibilities to spread production such that each location (country) shall contribute to the desired outsourced output in a specified manner. In essence, at the outset, the manager wants to evaluate the competitiveness of the alternative supply chains. His reasons are clear – there is no way of and no point in judging the individual suppliers performance because the reasons attributed to past failings in historical data mostly reflect infrastructural and institutional delays; and besides its a preliminary analysis. The production and other operations costs have already been determined and analysed. What he is now looking for is macro constraints that may impede providing 'time and place utility', or in other words supply chain operations and logistics constraints at a macro level.

Research objectives, approach and structure of the paper

Therefore the purpose of this article is to conceptualise at a theoretical level, a macro-institutional perspective of a supply chain and supply chain competitiveness. Here, the approach employed is an integration of theoretical paradigms, on how macro institutions are reckoned with when analysing *environmental complexity* affecting organisations, in International Business (IB) and Operations Management/Strategy (OM) literature. Whereas at a managerial level its purpose is to propose a decision-making framework, using the Analytic Hierarchy Process [AHP] (Saaty, 1980) as the dominant approach, which provides supply chain managers and supply chain policy makers with a tool to analyse macro-institutional constraints that impede effective supply chain management practice. Thus, whereas the first purpose seeks to establish the need and basis for adopting an institutional view of SCM, the second proposes and illustrates where and how such a view finds an application in a supply chain decision-making setting.

The structure of the paper is as follows:
After starting out with a presentation of a hypothetical problem at a managerial level which solution requires a macro-institutional perspective on supply chains, we discuss the results of a literature review. We then conceptualise a macro-institutional perspective on supply chains. Finally, we link the hypothetical problem to our conceptual framework and demonstrate its solution as an application of the macro-institutional perspective.

THE CONCEPTUAL FRAMEWORK

A review of supply chains and institutions in IJPE

It is interesting to note how existing literature on SCM treat supply chains and institutions. The supply chain is increasingly seen as a micro institution as a part of a broader supply chain macro institution, which means that the focus is on individual organizations or the interplay of individual organizations in a given setting. For example, in view of select International Journal of Production Economics (IJPE) publications, we could ascertain a prevalent micro-institutional focus in the study of supply chains and supply chain management:

Vonderembse et al. (2006) develop a theory for designing supply chains, where they differ between various supply chain types (lean, agile and hybrid supply chains) depending on the type of product that should be served to a market in a customer-required manner. The involved institutions refer to different supply chain actors, which are located along the chain (suppliers, manufacturers, distributors and customers) who perform different tasks in order to produce the demanded output. Institution, in this sense, may be interpreted as a supply chain actor, which is typically a firm. So we call this a micro-institutional focus as the rules of the games are devised on the level of micro-logistics.

Gunasekaran et al. (2004) develop a framework for measuring supply chain performance on an organizational level by adopting the SCOR-reference model to performance measurement. Based on the different phases of the SCOR-approach (make-order-delivery-plan) different performance measurers should be used to assess the power of the adopted SCM-approach. They also refer to the partnerships amongst the actors (= supply link and delivery link) but also refer to the measurement of customer satisfaction. The institutional understanding is one of companies, which we also call a micro-institutional focus.

Hameri and Paatela (2005) understand the supply chain as a supply network whose operational control is beyond the traditional borders of the organization. This understanding refers to Picot et al.'s (2001) borderless organization. The level of analysis refers to industries, however, the institutional understanding remains on a micro/meso-institutional level as the analysis refers to supply chain actors and yet the industry is also put in context.

Olhager and Selldin (2004) present results of a survey amongst Swedish companies. Supply Chain Management in their mind focuses on manufacturing firms and their long-term well being. In this paper, SCM can be understood as a type of inter-organizational planning because it is about ERP-implementation and integration. Again, this understanding can be interpreted as being micro-institutional.

Garavelli (2003) understands SCM as a form of networked businesses where plants optimally are connected with suppliers. Optimality implies that management can cope with internal and external variability. The network therefore needs a flexible configuration, so flexibility turns out to be an important driver for supply chain performance. Garavelli (2003) refers thereby to a flexibility of a total system but limits the system to a two-stage supply chain including the connection between assemblers and a plant or first-tier and/or second tier suppliers with a plant. A flexible supply chain configuration refers also to a flexible design of processes. Again, the institution refers to the actor-level, which to our mind is a micro-institutional understanding of the supply chain.

Hence, one prominent question remains – what about the setting in which these organizations are embedded? It seems that this setting is perceived as given and fixed. We think that the presented supply chain understanding is a consequence of the macro system, which should be analysed further.

What constitutes a macro-institutional perspective of supply chains?

It is fairly straightforward to conceptualise a macro-institutional perspective of a supply chain using an International Business (IB) paradigm. Following the lead of North (1990) "the environment can be subdivided into organisations, called… \`interactors', and institutions, called….the \`geovalent component'. Interactors comprise the organisations that interact directly with the firm - suppliers, customers and competitors. Interactors have other important properties: they can acquire other members (or be acquired), form alliances or simply cease to exist (liquidation/ bankruptcy). The geovalent component comprises all other environmental forces that impact on the firm but are not themselves organisations: institutional rules, regulations, cultures and exchange rates, for example", (Guisinger 2001, p. 266).

We form our understanding of a macro-institutional perspective based on Guisinger (2001). Although developed in the context of a multinational enterprise (MNE), his taxonomy of geovalent components (institutions) affecting the operations of MNE's helps us in developing a similar framework for analysing supply chains (Fig. 1), the central theme being "Geovalent adjustment of business processes". Following this perspective, a supply chain may be understood as an interorganizational arrangement embodying a high level of "structural complexity". A supply chain, when analysed in this context, has to adjust to its broader environment (e.g. a particular national environment, which may embody low to high environmental complexity depending on the geographical location), and thus achieve a synthesis of environmental adaptation and accommodation. This is what we term as the geovalent adjustment of supply chain processes, and using this interpretation we develop a framework for analysis of the environmental accommodation of these processes. We choose to study and demonstrate the environmental accommodation aspect (Fig. 1); this is also what North's (1990) institutional perspective calls for.

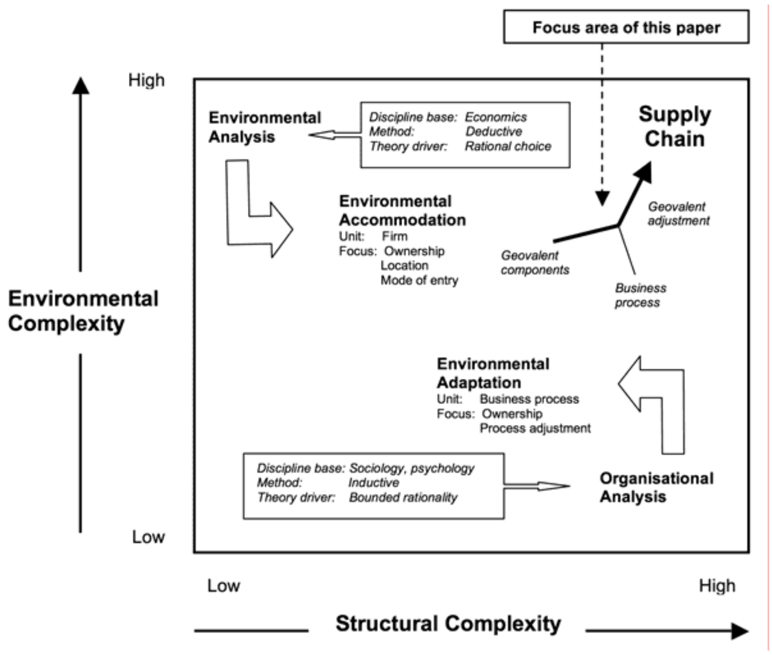

Fig. 1. Geovalent adjustment as synthesis of adaptation and accommodation approaches (Adapted from Guisinger, 2001).

The management of such chains is of increasing academic interest (Harland et al., 2006) and it has an inherent holistic and global outlook as it sought to transform from a logistics management perspective to a wider perspective (Rudberg and Olhager, 2003). Whereas "manufacturing network" theory, which can largely explain MNE activity, has an intra-firm orientation with focus on the number of nodes or sites within the same organization, "supply chain" theory has an inter-firm orientation with its focus on the number of links or organizations within the same network. Their complementary nature, global outlook, and complex organisational structures (Rudberg and Olhager, 2003), however makes the two contexts interchangeable, above all because they face similar environmental complexity when faced with multiple institutional environments.

Antecedent and complementary theoretical insights to the macro-institutional supply chain perspective

It is also important to understand the background within which a macro-institutional perspective is embedded. Within Operations Management/Strategy literature there has been a long-standing research tradition emanating as early as Skinner (1969) that advocates the importance of a 'fit' between firm strategy, its environment and performance. In short, there should not only be a fit between firm strategy, its environment and its performance but also that the environment triggers firm strategy, which in turn adapts and adjusts to achieve performance. We refer to this fit as the *environment-strategy-performance* relationship hereafter. Starting from the seminal contribution of Swamidass and

Newell (1987), where they empirically test their contingency theory based model of this relationship, there have been others who have explored its specified causality, importance and consequences in the form of strategy formulation and managerial decision-making (e.g. Ward et al., 1995; Williams et al. 1995; Badri et al. 2000; Ward and Duray 2000; Anand and Ward 2004). Fig. 2 provides a conceptual model that Ward and Duray (2000) test in the *environment-strategy-performance* relationship.

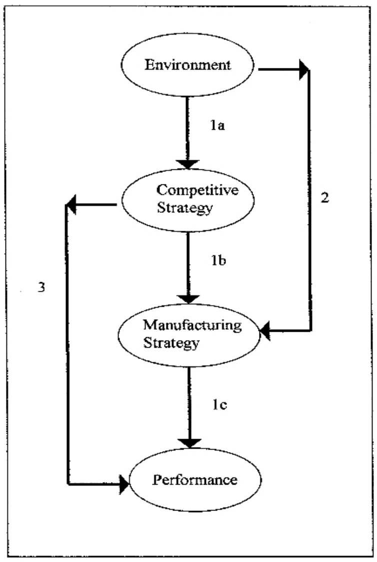

Fig. 2. Conceptual model of manufacturing strategy in its context (source: Ward and Duray, 2000).

Besides the in-depth exploration and operationalisation of each of the three fit variables in this research tradition, an aspect that sheds utmost light on a macro-institutional perspective is how they have treated the environment. For example, a detailed exploration is carried out on such attributes of the environment as munificence, dynamism and complexity (though complexity is left out in most studies because it forms a part of domain seeking decision-making). The environment components (especially the complexity attribute) in this research stream are in fact to be understood as a commonality shared with Guisinger's (2001) "geovalent components". Environmental *complexity* in this research stream "refers to the heterogeneity and range of an organization's activities" (Child, 1972, p. 3). As mentioned in the previous section, Guisinger (2001) advances a conceptualisation of increased environmental complexity in the case of structurally complex organisational forms such as MNE's and supply chains, more so when multiple national (institutional) environments are to be incorporated in the equation. The macro-institutional factors affecting business operations in this case are termed as "geovalent components" and represent factors such as econography, culture, legal systems, political risks, government restrictions etc. (Guisinger, 2001).

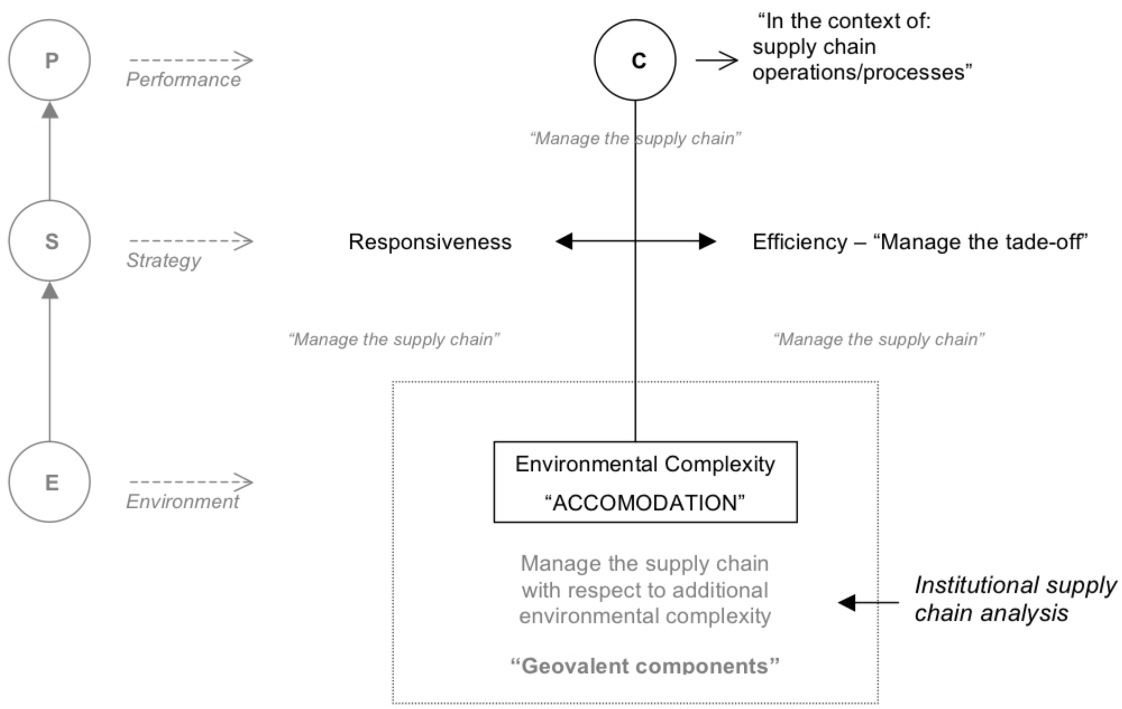

Fig. 3. Conceptual framework: the 'fit' between supply chain environment, strategy and performance.

Thus, the *environment-strategy-performance* relationship presents an opportunity for understanding the background of the macro-institutional perspective and helps determine a more precise application of any institutional analysis in terms of an activity (e.g. strategy formulation, decision-making), an organisation (e.g. firms, MNEs, supply chains) and a problem owner (e.g. production/operations managers, supply chain managers, policy makers). Based on the discussion, it is easier to visualise the background, nature and consequence of a macro-institutional perspective in SCM through Fig. 3., which is fundamentally an integration of ideas presented in Fig. 1 and 2. "C" represents competitiveness, and is to be seen as an effect of a comprehensive strategy making process, which itself arises from an environmental analysis in a specific context of supply chain management operation, process or practice.

To summarise, our understanding of an institutional view of supply chain assumes a macro-institutional perspective, as we are interested in the 'super-constraints', which impact the constraints on a micro-logistics level. The super-constraints have consequences for managers as the macro-institution determines the output of the micro-institution, which in the business logistics literature has constituted the notion of systems thinking (Bowersox and Closs, 1996; Pfohl, 2004). Similarly, assuming a macro-institutional perspective has also consequences for policy makers as they influence the provision of supply chain infrastructure.

This implies taking into consideration macro level institutional constraints while designing business processes, flows and activities. Similarly, at a strategic level, we understand the incorporation of these constraints into decision-making e.g. choice and selection of best alternatives. This means that firms, their supply chains and their processes are embedded in a macro-institutional context (geovalent conditions), which presents not only conditions of munificence but also complexity and constraints to their operations; the nature and severity of these conditions depends on the scope or the structure of business operations. For example, a domestic firm in a single country environment faces less of these conditions as compared to a multinational firm representing an intra-firm network and operating in different international environments, as compared to a complex global supply chain with an inter-firm focus. Adjusting to these conditions is what a macro-institutional perspective stands to advocate.

State-of-the-art within a macro-institutional perspective
This approach of visualising macro-institutional issues and constraints facing organisations and managers has found itself application within operations strategy literature where “site location” is an important structural decision criterion, when the question of production or manufacturing facilities arises (Hayes et al, 1988; Skinner, 1996; Hill, 2000). Herein under, access to low-cost production, access to skills and knowledge and proximity to markets are important considerations (Ferdows, 1989; Ferdows, 1997). As a result, macro constraints that impede site-selection have been incorporated in modelling studies (e.g. Kugel, 1973; Badri, 1999; Todd, 1977; Badri et al., 1995; Badri, 1996). Moreover, global factors affecting organisational operations (structural and infrastructural decision criteria) as a result of international and MNE activity have been modelled as well (see Bhutta et al., 2003; Hadjinicola and Ravi Kumar, 2002).

Similarly, within the IB stream, authors have focused on these issues for long. Large chunks of research namely “cross-border production networks” (e.g. Zysman et al, 1997; Borrus and Zysman, 1997) and research within the “multi national corporation” (e.g. Buckley and Casson, 1976; Rugman 1976) have focussed on “site location” issues, though from a different theoretical perspective e.g. Internationalisation, Internalisation and Industrial Organisation theory. Apropos, country studies such as the World Competitiveness Yearbook (WCY) and the Global Competitiveness Report (GCR) seek to measure competitiveness at a national level by ranking different country environments and institutions. However, in the absence of an undisclosed and confidential methodology, as in the case of the WCY, there have been calls from researchers (Oral and Chabchoub, 1996; Zanakis and Becerra-Fernandez, 2005) in developing other techniques and modelling methods that can help in better understanding and structuring such an institutional analysis.

Within the SCM stream, a macro-institutional perspective represents an emerging trend. Bagchi (2001) presents a framework to assess supply chain competencies of a geographically and economically defined entity (=nation), supply chain competency implying and defined as the nation’s ability to sustain top class supply chain management practices, institutions and infrastructure. Hausman et al. (2005) present “global logistics indicators” in order to focus attention on reducing sources of logistics friction faced by organisations involved in cross-border trade and as a way to increase their country’s ability to compete in a global economy. In most cases these studies are still in development.

CONSEQUENCE: A MULTI-CRITERIA DECISION PROBLEM?

According to Zimmermann (2005), the basic characteristic of a multi-criteria decision problem is a goal conflict, as different decisions with different objectives have to be solved instantaneously e.g. reducing logistics costs and speeding up lead times. The goal of any algorithm for solving such problems is to calculate or to select the most advantageous solution that a decision maker prefers most with regard to all objectives (Zimmermann, 2005).

We propose that the analysis of the *environment-strategy-performance* relationship in supply chains, best represents a decision-making problem as the manager of the individual firm simultaneously tries to optimise his firm's performance, while faced with the task of synchronising this performance across the supply chain (as interpreted through Rudberg and Olhager, 2003). Furthermore, even within this broad ambition, sub-analyses are called for (see Fig. 3). For one, how does the manager/s characterise the environment as being complex? If Guisinger's (2001) idea about environmental complexity is to be interpreted as the increase in total number of factors representing geovalent conditions (i.e. institutional rules, regulations, cultures, exchange rates etc.), how does the manager classify and rank the importance of each as affecting his firm and the firm's supply chain?

Next, following our approach in Fig. 3, the determined complexity and/or dynamism should in effect trigger another set of decision-making processes, which shall determine the need, type and composition of competitive and operations strategy, i.e. a responsiveness-based and/or a cost-based strategy. Also within this, does responsiveness in the context imply a delivery-based concept of speed (as measured for e.g. by Ward and Duray, 2000 in terms of providing fast deliveries and meeting delivery promises etc.), or flexibility-based concept of agility (measured in terms of lead-time reduction, set-up time reduction etc.)? Similarly, an efficiency-based strategy of reducing costs is also dependent of many variables such as reducing inventory, reducing logistics costs etc. Next, if the notion that trade-off's exist between responsiveness and efficiency, but only given that the cost-responsiveness efficiency frontier has been achieved (Chopra and Meindl, 2007) is to be incorporated, there is an implication that each strategy is important and may be followed at the same time. Then an equally important question is that of how important is each strategy's role, given a certain environment classification, such as complexity. Last but not the least, these analyses have to be carried out, while defining and keeping performance in mind and in context.

Therefore the best way of approaching the problem is by seeing it as multi-criteria decision problem, because there is a wealth of available alternatives while categorising and operationalising the *environment-strategy-performance* relationship, more so considering the added environmental and structural complexity posed by incorporating a supply chain context.

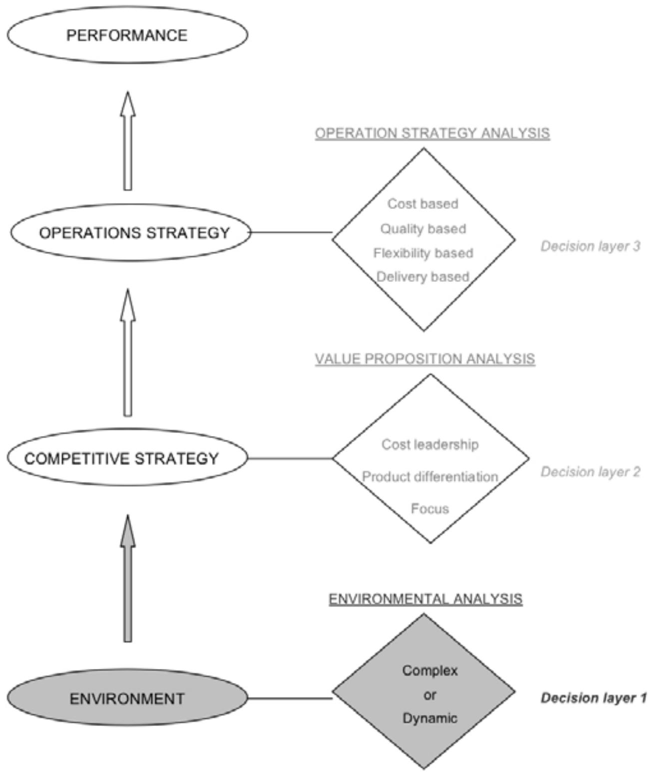

Fig. 4. Achieving 'fit' as a multi-criteria decision problem.

Fig. 4 elucidates at least three decision-making sub-analyses resulting out of our conceptual framework. Here, performance is the consequence or goal, environment an input, and strategy a mediator. Once we accept the attainment of the goal (performance) as a multi-criteria decision problem, we are calling for this entire system to be analysed under a corresponding (e.g. a decision-making) methodology. In effect, this requires that multiple levels of analyses be performed in order to maintain the state of fit (*fit as mediation* in this case), between the environment, strategy and performance components. The macro-institutional understanding is engrained in the environment.

APPLICATION

It should be noted, however, that in the present paper we shall restrict our analysis to 'Decision layer 1' (see Fig. 4). This is the decision layer we find most relevant while studying macro-institutional constraints affecting SCM. Using this as a point of departure, we illustrate the application of a macro-institutional perspective of SCM while carrying out an environmental analysis. This environmental analysis in our illustration takes the form of an illustrative decision-making problem centring on selecting the nation/s that provide the best environment and possibilities for sustainable supply chain operations and practices (see p. 3 "The underlying problem").

The approach – the AHP approach for a supply chain competitiveness model

We use the AHP (Saaty, 1980) to develop a model for assessing and measuring supply chain competitiveness. The AHP approach shall result into an illustrative model that assesses the capabilities of individual nations in their ability to sustain top class supply chain management practices, institutions and infrastructure. This is defined as *Supply chain competitiveness of nations,* and using the framework for analyzing geovalent elements affecting effective operations of supply chains in a national environmental context, we compare this ability for the choice group of countries. The theoretical approach here represents a macro-institutional perspective of SCM, a point that has been established through our conceptual framework (see Fig. 3).

"A hierarchy of supply chain competitiveness" – methodology

Our stance on the AHP presumes and demonstrates that an application of this methodology inadvertently results in a framework, which provides the requisite breadth and flexibility in performance visibility, and thus results in a model for capturing competitiveness. Using the AHP, we structure our problem i.e. geovalent elements (environmental conditions/ macro level infrastructural and institutional factors) affecting the assessment and measurement of supply chain competitiveness in the following manner:
1). We position supply chain competitiveness as the apex (overall goal); 2). Following Handfield and Nichols (1999) and Bowersox and Closs (1996), we establish the objectives of attaining supply chain competitiveness as the optimisation of the four flows: physical flows, information flows, payment flows and ownership flows; 3). Following Bagchi (2001), we consider that geovalent elements that affect these four flows at a national (macro) level may be characterised as: physical infrastructure factors, institutional factors and technology diffusion factors; 4). Next, we breakdown the geovalent elements into specific factors, which correspond to each of the four respective flows; 5). Lastly, the BRICs (Brazil, Russia, India and China) countries are compared to each other and a standard country, based on the diverse groups of geovalent factors. The standard country is taken as USA; standard implies the benchmark in terms of all factors considered and is assumed, based on the consistently high overall ranking for the US in indexes such as IMD's World Competitiveness Index. In this sense, a goal-oriented approach is applied. This comparison demonstrates the *Supply chain competitiveness of nations* in sustaining effective operations of supply chains within their geographical scope. The structure of this framework is presented in Fig. 5. where we suggest phrasing the supply chain competitiveness of nations as "Macro-institutional supply chain competitiveness".

Data collection

Our aim is to provide an illustration of the presented analytical framework and we create a simple model for *Supply chain competitiveness of nations*. By simple we imply that we compromise on the complete meticulousness required to realise full potential of the framework. Moreover, simple also implies the application of AHP here as a stand-alone methodology, which when paired with another methodology e.g. goal programming (Badri, 1999), cognitive mapping (Suwignjo, 2000), can significantly enhance the capability of the resulting model. A more detailed description of the methods in operation, data collection and limitations is provided in Appendix 1. Data representing each factor analysed, was collected on the measures provided through the grid in Exhibit 2.

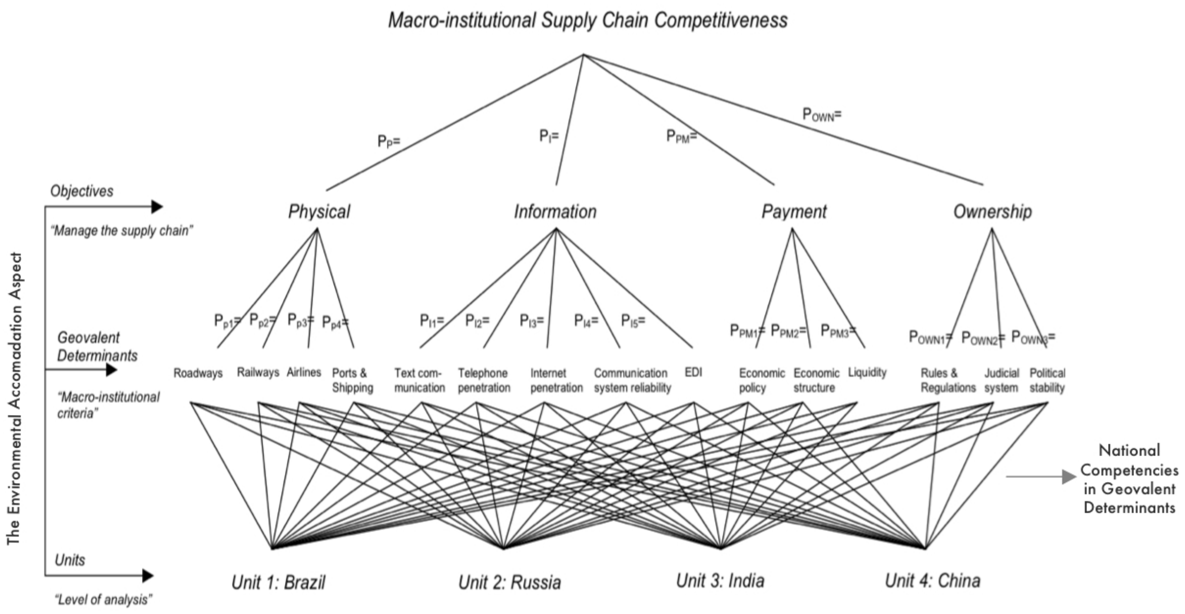

Fig. 5: A hierarchy of a macro-institutional supply chain competitiveness.

Discussion of results

Having arrived at the respective weights for the 4 flows and the respective weights for the corresponding factors of each flow, the last steps of the synthesis process and an illustration of the process of deriving a supply chain competency index is briefly described as under:

For each of the 13 evaluation criteria (15 factors originally considered as in Fig. 5 and later on consolidated into 13 evaluation criteria), a 5 x 5 matrix was produced, which was used to determine the preference vector for this matrix. The 5 x 5 matrix implies, the pair-wise comparison of the 5 units i.e. the four BRICs countries and the standard (US), over each factor considered. Data available through the grid (Exhibit 2) was used to carry out this comparison, and as per the norm, a 1-9 ratio scale was used. Therefore, a total of 13 such matrices were constructed and a total of 13 preference vectors were produced. An example of one such matrix is given through Exhibit 1, which describes the pair-wise comparison of the 5 countries in “Quality of Road Transportation”. We used Expert Choice® software (2004, v. 11) to structure the hierarchy, decomposition, analysis of the collected data for each country and synthesis of results.

Fig. 6 shows the preference vectors for each of the 13 matrices (one for each factor), arranged by the corresponding flows of the factors, and arranged for the 5 units that are compared. Thus, we developed 4 such matrices, one for each flow. The physical flow matrix is a 4 x 5 matrix because of the 5 countries’ values in the matching 4 factors of the flow, and likewise the information, payment and ownership flow matrices are 3 x 5 matrices due to the 5 countries’ values in the 3 factors of each of these three flows. Next, each of the 4 developed matrices, were charted and multiplied with their respective priorities/weights/ preference vectors of the (4+3+3+3) factors, and multiplied further on with their respective priorities/weights/preference vectors of the (4) flows. In this manner, a relative ranking of the four BRICs countries was produced.

Quality of Road Transportation	Brazil	Russia	India	China	US
Brazil	1	1/2	1/8	1/4	1/9
Russia	2	1	1/5	2	1/9
India	8	5	1	2	1/4
China	4	1/2	1/2	1	1/7
US	9	9	4	7	1

Exhibit 1. Sample matrix

	A. WDI 2005, World Bank	B. World Competitiveness Online 2005
Quality of Road Transportation	1). Total road network in kms (1997-2002), 2). Paved roads, % of total road network (1997-2002), 3). Goods hauled by road in ton-km, 4). Motor vehicles per km of road, 1990, 5). Motor vehicles per km of road, 2002	1). Density of the network 1998-2002
Quality of Rail Transportation	1). Total Rail Lines route in kms (2000-03), 2). Goods hauled by railway in ton- km (2000-03)	1). Railroads measured by density of the network (1999-2003)
Quality of Air Transportation	1). Air freight, ton-km, 2003	1). Air transportation – no. of passengers carried by main companies (1999-2003), 2). Quality of Air transportation, survey (2002-2005)
Quality of water transportation	1). Container traffic (TEU)	1). Water transportation, survey (2001-2005)
Text Communication (mail & fax)	Reliance on values and rankings of countries in this factor from previous study i.e. Bagchi (2001).	
Telephone Penetration	1). Telephone mainlines per 1,000 people (2003), 2). Telephone mainlines in largest city per 1,000 people (2002), 3). Telephone mainlines per employee (2003)	1). Mobile subscription per 1,000 inhabitants (1999-2003), 2). Fixed telephone lines per 1,000 people (1999-2003), 3). Investment in telecom, % of GDP (1999-2003)
Internet penetration/ IT infrastructure/ EDI	1). Personal computers per 1, 000 people (2003), 2). Information and communications technology expenditures, % of GDP (2003)	1). Computers per 1,000 capita (2000-2004), 2). Broadband subscribers per 1,000 people (2002/03), 3). Internet users per 1,000 people (2002-2004), 4). Communications technology, survey (2004/2005)
Economic policy conduciveness	1). Policy uncertainty is a major constraint, survey (2002-2003)	1). Central bank policy, survey (2001-2005), 2). Policy direction of government, survey (2001-2005), 3). Transparency, survey (2001-2005)
Economic structure conduciveness	1). Corruption, survey (2002-2003), 2). Labour skills as a major constraint, survey (2002-2003), 3). Labour regulations as major constraints, survey (2002-2003), 4). Net income in million Dollars (1990, 2003)	1). Banking and Financial services, survey (2002-2005), 2). Bribing and corruption, survey (2001-2005), 3). Country credit ranking (2001-2005), 4). Credit card transactions per capita (2000-2004), 5). Resilience of the economy, survey (2002-2005), 6). Bureaucracy, survey (2002-2005)
Liquidity		1). Cash Flow, survey (2001-2005)
Rules and Regulations	1). Average time to clear customs days, 2). Enforcing contracts (time required days)	1). Labour Regulation, survey (2001-2005), 2). Regulation Intensity, survey (2005), 3). Legal and regulatory framework, survey (2001-2005), 4). Ease of doing Business, survey (2003- 2005), 5). Customs Authorities, survey (2001- 2005), 6). Public service, survey (2001-2005)
Judicial system	1). Courts as a major constraint, survey (2002-2003), 2). Lacking confidence in courts as a major constraint, survey (2002-2003)	1). Business Legislation ranking (2001-2005), 2). Competition Legislation, survey (2001-2005), 3). Immigration laws, survey (2001-2005), 4). Justice, survey (2001-2005), 5). Product and service legislation, survey (2001-2005
Political Stability		1). Risk of political instability, survey (2001-2005)

Exhibit 2. Data Grid

In summary, the index was produced using the following approach:
1). Aggregate score in a factor for a unit (country) = [priority based on the preference vector for that factor for the country] x [priority based on the preference vector regarding the relative importance of that factor in representing its corresponding flow] x [priority based on the preference vector regarding the relative importance of the corresponding flow in determining supply chain competitiveness]
2). Accordingly, total score for the unit (country) = the sum of aggregate scores in all the factors for the country.

			Preference/Directional vectors achieved through pair wise comparisons					
Flows	*Factors*	*Priority*		**Brazil**	**Russia**	**India**	**China**	**US**
Physical Flows		**.45**						
	Quality of Road Transportation		***.439***	.034	.062	.204	.101	.598
	Quality of Rail Transportation		***.255***	.023	.073	.131	.145	.629
	Quality of Air Transportation		***.133***	.011	.007	.004	.024	.953
	Quality of Water Transportation		***.173***	.059	.050	.038	.164	.690
Information Flows		**.30**						
	Text Communication		***.100***	.083	.207	.050	.083	.579
	Telephone Penetration		***.500***	.140	.150	.036	.118	.555
	Internet Penetration/ IT infrastructure/EDI		***.400***	.069	.101	.012	.025	.794
Payment Flows		**.20**						
	Economic Policy Conduciveness		***.250***	.072	.031	.200	.037	.661
	Economic Structure Conduciveness		***.300***	.060	.042	.282	.062	.553
	Liquidity		***.450***	.143	.067	.209	.228	.353
Ownership Flows		**.05**						
	Rules & Regulations		***.333***	.061	.090	.126	.326	.397
	Judicial System		***.333***	.093	.035	.152	.156	.565
	Political Stability		***.333***	.222	.076	.196	.169	.337
GOAL: Macro-institutional supply chain competitiveness				**.081**	**.081**	**.133**	**.124**	**.581**

Fig. 6. Supply Chain Competitiveness Index.

Two things can be evident from this illustration. First, the numbers generated after the synthesis process was finished represent a (preference/directional) vector; the entire process of arriving at these numbers is based on the Eigen value approach and these numbers signify priorities or weights. Since these numbers, when put together represent a vector, they will always fall in a realm of 0 to 1, and when added will always sum up to 1. Second, and as a consequence, the final directional vector represented by *GOAL: Macro-institutional supply chain competitiveness* in Fig. 6, is used to determine the overall ranking of each country in supply chain competitiveness, based on the principle - the higher the priority/weight derived, the higher shall be the ranking. Therefore, the US ranks the highest (1st), followed by India (2nd) and China (3rd) respectively that are almost similar in their overall supply chain competitiveness, followed lastly by Brazil and Russia (both 4th). Furthermore, one may also track down exact differences between these 5 countries individually by flow and/or by factor to determine where exactly one lacks over the other and by how much, which will help the decision-maker in carrying more advanced analyses according to e.g. product nature, demand characteristics, resource allocation etc.

CONCLUSION AND OUTLOOK

It is rather important to understand the macro-institutional context in which supply chains, their functions and processes are embedded. As Badri (1999) rightly points out, decision-makers can no longer ignore the influence of location specific factors such as government regulations, policy, infrastructural and political conditions, especially when the present nature and context of operations demand structurally complex organisations (e.g. supply chains) and environmentally complex environments (e.g. international or global locations). A supply chain faces added environmental complexity because of wider geographic distribution of activity, which imposes additional constraints as a result of e.g. global and cross-national activity. This fact is at least evident in the case of 'outsourcing' and 'offshoring' of business activity. In view of this, it becomes imperative to consider the macro-institutional constraints that impede supply chain activity and performance.

This paper has presented a conceptual framework, which not only elaborates what a macro-institutional perspective on supply chains represents, but also the background of its embedment. The theoretically derived conceptual framework presented in Fig. 3 elaborates the context of a macro-institutional perspective, while at the same time linking it with specific structural decision-making criteria at the micro levels e.g. supply chain operations and performance. Such treatment made it possible for us to further translate our conceptual framework into an illustrative decision-making problem faced by a supply chain manager vis-à-vis outsourcing, and to thereby demonstrate the assumption of a macro-institutional perspective in action while dealing with a supply chain "location" problem. This was done using the Analytic Hierarchy Process (AHP) and a tool for the analysis of the supply chain (macro) environmental complexity was suggested.

The contribution of the present paper has been to present an alternative macro-institutional orientation, to the predominant micro-institutional formulations of supply chains and supply chain activity in the domain (e.g. IJPE). Moreover, it has linked the two using the conceptual framework presented in Fig. 3. Next, this paper has presented an explicit theoretically derived framework, which provides the very basis that a macro-institutional perspective of supply chains lacks in the domain. Finally, it has demonstrated managerial implications in the form of a decision-making problem and has suggested a simple model to incorporate macro-institutional constraints while dealing with site location and selection.

APPENDIX 1 - *METHODS AND DATA (LIMITATIONS)*

We do not analyse the flows for construct validity and reliability; nor do we test the factors for the same. We take them as given based on previous studies that have incorporated these. We do not test the flows or the factors for mutually exclusivity. For example, we are aware of the Analytic Network Process (ANP), which is a higher level multi-criteria decision making tool and which gives the option of horizontal-level comparisons (interactions and dependencies within the horizontal level) and vertical feedbacks in structuring systems, as opposed to the only straight down comparison possibility given by AHP (Saaty, 1996; Meade and Sarkis, 1999).
Level 2 hierarchy - the 4 flows (Physical, Information, Payment and Ownership): a good example of data collection here is a survey (Chan and Lynn, 1991), where the respondents (e.g. 3-4 respondents from different industry sectors) answer a questionnaire, which will help in the ranking/assigning weights to the 4 flows.
Level 3 hierarchy – the 13 factors, each factor corresponding to a certain flow i.e. 4 physical flow factors + 3 Information flow factors + 3 payment flow factors + 3 Ownership flow factors: the first step is to repeat the process as in the previous level and to determine the rank/weight/contribution of each factor towards its corresponding flow. Here again, we have forgone a detailed analysis and data collection, for example in the form of a survey, where respondents answer a questionnaire (Chan and Lynn, 1991), which assists in the assignment of weights to the 16 factors. In this step, we assume the reliability of weights derived for these factors in Bagchi (2001), and proceed with the analysis.
Next, we define how these (13) factors shall be measured. Then data is collected for these metrics using databases for the 4 units (the 4 BRICs countries i.e. Brazil, Russia, India and China) and the standard unit (US), presently available to the best possible extent. Firstly, the data collected for these factors, may not always be exactly representative. Secondly, the data representing these metrics may be in a mix of qualitative and quantitative formats. This implies that certain metrics, especially those that are of a qualitative nature, have been measured using subjective surveys.
A grid containing the 13 factors, performance measures/metrics used to represent each factor and its corresponding value for each of the units (countries) examined, is subsequently manufactured. Here we use secondary and tertiary data collected via published and online research data-bases such as World Bank i.e. World Development Indicators (WDI) Online, World Competitiveness Yearbook (WCY) sources i.e. World Competitiveness Online, Economic Intelligence Unit (EIU), Eurostat Yearbook, Global Development Finance (GDF) Online and Source OECD.
Lastly, as a beginning of the synthesis process, one may (preferably) ask the respondents (e.g. through a questionnaire) to rank (on a 1-9 scale) different countries for each factor. As background information, one can also provide them the grid (with hard data values) made in the previous step, so that they can make qualified decisions. In this step, we have foregone the comparative judgement process using different respondents once again, and for the purposes of illustration have used the grid of corresponding data values to rank the countries ourselves.

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The Contribution of Organization Theories to Supply Chain Management Research

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Abstract:

The objective of this article is to provide scientists with an instrument for selecting appropriate organization theories for the investigation of certain classes of SCM problems. Based on a literature review, a set of criteria for the evaluation of organization theories in a SCM context are presented which provide answers to the questions *why, who, what, how, where* and *when*. Moreover, the transferability of core organization theories to SCM is assessed. These are institutionalist theory, contingency theory, transaction cost economics, property rights theory, agency theory, network theory, and population ecology.

Keywords:

Supply Chain Management, Network Theory, New Institution Economics, Contingency Theory, Institutionalism

1 Introduction

The term Supply Chain Management (SCM) first appeared in the 1980’s (Oliver and Webber, 1980) due to the challenges a globalized economy presented and the increasingly emergent reasoning in processes and interlinked interorganizational value chains associated with Porter (Porter, 1981 and 1985). Since then, SCM has steadily grown in importance (La Londe and Masters, 1994, p. 35-37). This development was facilitated by the advancements of information technology which considerably contributed to the reduction of complexity and promoted the idea that processes might be integrated across companies.

However, until today, research and practice have not yet agreed upon a generally accepted comprehension of SCM. Whereas researchers from various functions assign different meanings to the term, the situation becomes even more confusing when perspectives from various cultural backgrounds, such as the USA, Europe and Asia, are taken into account. For example, in the United States, logistics management is often viewed as a subordinate function of SCM (e.g. Gibson et al., 2005, p.22). SCM is frequently considered to be a synonym or part of strategic logistics management in other countries, for example in Germany. In addition, more and more disciplines incorporate SCM and supply chain rational into their fields of study: strategic management (e.g. Bechtel and Jayaram, 1997; Christopher and Ryals, 1999; Tan, Lyman and Wisner, 2002; Ketchen and Giunipero, 2004), purchasing and supply management (e.g., Leenders et al., 1994; Stuart, 1997; Jahns, 2005), marketing (Svensson, 2002, and 2003; Min and Mentzer, 2000) and operations management (e.g. Khouja, 2003) - to name only a few. The objectives pursued, the scope covered and the methodologies applied for scientific research by these disciplines largely differ.

The broad usage of the term, its varying definitions and the numerous characteristics attributed to SCM led to a claim for more general theoretical underpinning of the SCM approach (e.g. New, 1995, p. 19-20; Mentzer et al., 2001, p. 3). As Stock points out, the application of other theories to SCM can profoundly contribute to the establishment of a theoretical fundament for SCM research. He identified three benefits existing theories might have: First, it enables learning from the experiences others have already made. Second, it advances the knowledge and understanding of a phenomenon that might have occurred later or not at all. Third, it increases the linkage among the different disciplines taken into consideration (Stock, 1997, p. 16). Accordingly, Stock presents a large list of theories which might provide new and valuable insights when applied to SCM. The article from Stock inspired numerous scientific works in which one of the proposed theories was applied to a certain SCM research question. The popularity of the approach is apparent by the fact that the Journal of Operations Management recently dedicated a special issue to the integration of insights from organization theory to SCM (Ketchen and Hult, 2006).

However, the field of economic theory is extraordinarily large, as is the field of SCM. Researchers who propose a certain theory are inspired by different scientific paradigms, ranging from positivism to interpretivism. The question still remains whether there are specific theories that might be more suitable for certain SCM questions than others. Therefore, the objective of this article is to propose evaluation criteria that integrate an assessment of theories and their transferability to SCM questions. These criteria then serve to systematically assess the contribution potential of certain theories for SCM research.

In order to achieve this objective, we will first review existing literature on SCM to discern key elements and core characteristics associated with the term. In a second step, a set of evaluation criteria for the applicability of theories from other disciplines to

SCM will be elaborated. Finally, one of the broadest fields of theories usually applied for the investigation of SCM issues, namely organization theories, will be analyzed using this defined set of criteria.

2 Literature Review

In this section, a definition of the term Supply Chain Management and an overview of the reasons for SCM's success will be provided. In addition, core theoretical models of SCM will be presented to discern general aspects of SCM's composition as suggested by scientific researchers.

Within literature, there has not been a consistent usage of the term SCM to date. Several definitions have been proposed since the first application of the term. Jones and Riley (1985) provide one of the first definitions by stating that SCM is concerned with the flow of goods from the initial supplier to the end user. Ellram and Cooper (1993) suggest that SCM is an integrated philosophy of managing the whole flow of an entire distribution channel. Another perspective is adopted by Christopher (1992), who described SCM as a network of organizations that are involved in different value producing activities. Mentzer and colleagues provide a holistic definition of SCM that encompasses the numerous aspects of SCM. "S*upply chain management is defined as the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole*" (Mentzer et al., 2001, p. 18). This definition neither restricts a supply chain to inner-company processes nor to certain functions and tasks. Therefore, this definition of SCM will be adopted for the purposes of this paper.

The success of SCM since its emergence in the 1980's, is associated with several reasons. SCM has become popular due to the ongoing concentration on core competencies, an associated trend towards outsourcing, and the effort to maintain some parts of control over outsourced activities by means of vertical integration (Lummus and Vokurka, 1999, p. 12). SCM is frequently seen as a result of globalization and increased international competition (Christopher, 1992). From this perspective, SCM can be interpreted as an instrument to react more flexibly to individual customer demands, to decrease delivery times, and to reduce inventory stocks by improving information sharing. SCM may be a signal that organizations are aware that performance maximization within one unit can lead to a its decrease of the overall supply chain. Thus, organizations that are directly linked in a supply chain attempt to synchronize their activities in order to achieve an overall increased benefit (Lummus and Vokurka, 1999, p. 12).

The increased popularity of SCM among practitioners led to an equivalent response within the scientific community. The number of articles, books and other forms of publications is steadily expanding. In the following paragraphs, we will present some of those scientific works that deal with the theoretical conception and substantiation of SCM.

Christine Harland was one of the first authors who provided a theoretical classification of SCM, by proposing four different types of supply chains. First, the *internal supply chain* integrates all business functions which are involved in the flow of materials and information from inbound to outbound business. Second, the *dyadic or two party supply chain relationship* which incorporate the management of direct partners and immediate suppliers. The third supply chain involves a *chain of businesses*: supplier, supplier's suppliers, customer, and customer's customers and so on. Finally, Harland distinguishes the fourth supply chain as the management of a *business network* involved in the provision of products and/or services required by the final user (Harland, 1996, p. S64).

Cooper et al. (1997) are not only interested in the number of organizations involved in a supply chain, but also in the scope of responsibility of the focal firm. They distinguish four types of SCM: In a *dyadic relationship*, organizations focus only on those channel members with whom they are in direct contact. The *channel integrator* plays the key role both in setting the overall strategic objectives and in obtaining the commitment of all channel members to this strategy. In an *analytic optimization* orientation, the channel leader determines the optimal supply chain configuration by the use of computerized modelling. Finally, in a *vertical integration* situation, the channel integrator owns part of the other channel members.

Another conceptual framework that emphasizes the interrelated nature of SCM has been developed by Cooper, Lambert and Pagh (1997, 2000). This framework comprises three closely interrelated elements: the supply chain network structure, the supply chain business processes and the supply chain management components. The *supply chain network structure* deals with the firms participating in the supply of goods or services, ranging from the raw material supplier to the ultimate user. When managing the network structure of a supply chain, organizations need to take into consideration: the number of partners included in the supply chain, the closeness of the different types of relationships (differentiated into primary and supporting members), the structural dimensions of the network (its horizontal structure, its vertical structure and the position the focal company has within the network), and the different types of process links across the supply chain (classified into managed process links, monitored process links, non-managed process links, and non-member process links). The task of *supply chain business processes* is to integrate activities across companies to develop them into key supply chain processes. Some of the key functions identified are: customer relationship management, customer service management, demand management, order fulfilment, manufacturing flow management, procurement, product development and commercialization, and returns. Finally, the *management components of SCM* are concerned with all those components of a supply chain that need to receive managerial attention. In essence, nine components have been identified: planning and control, work structure, organization structure, product flow facility structure, information flow facility structure, management methods, power and leadership structure, risk and reward structure, and culture and attitude (Lambert and Cooper, 2000, pp. 69-78). The proposed framework of Cooper, Lambert and Pagh provides a structured overview of the different functions, departments and hierarchical levels concerned with and involved in SCM.

Another conceptual framework has been proposed by Giannakis and Croom (2004). Unlike the two previous models which are more concerned with the structure and possibilities to manage a supply chain, their proposed "3-S-framework" also incorporates different types of objectives pursued with SCM. The *synthesis dimension* relates to the physical structure of a supply chain and is close to the chain network structure, as proposed by Lambert, Cooper and Pagh. Within this dimension, managers are concerned with decisions relating to the strategic position of a firm within a supply chain, the extent and scope of vertical integration, supply base configuration, and the selection and structure of channels to customers. The *synergy dimension* focuses on decisions about the nature and influence of interaction among actors in a supply chain including supplier selection, customer relationship management, and inter-organizational behaviour. Finally, the *synchronization dimension* is substantiated by findings from the logistics, operations management, operational research, industrial engineering literature and involves decisions about scheduling, coordination, information management and materials flow analyses (Ginnakis and Croom, 2004, p. 32). This last dimension is closely related to the business process components of a supply chain as defined by Cooper, Lambert and Pagh and adds an objective of synchronization to the identified functional areas.

Both the 3-S model and the framework from Cooper, Lambert and Pagh allude to the importance of ‘soft’ factors, such as culture, power and relationships of actors in a supply chain. Despite this suggested importance, the two models do not provide a clearer picture of these aspects. Andrew Cox mainly addresses the power question (Cox, Sanderson and Watson, 2001; Cox, 2004 and 2001). Depending on the degree of power a buyer and a supplier have within a supply chain context, Cox distinguishes between buyer dominance, supplier dominance, independence and interdependence. Accordingly, the mode of cooperation varies. In a situation of independence, the exchange partner pays the current market price without aggressive bargaining but tests the market excessively (non-adversarial arm’s length). Thus, Cox attempts to overcome the lack of theoretical investigation of the `soft` aspects of SCM. However, research into these still needs to be considered in its early stages and requires more attention in the future. From the existing work, it can be ascertained that managers within a supply chain need to be concerned with the relative position of their own company in the overall chain.

The presented frameworks are only a few of the vast number of scientific and practitioner oriented models that have been proposed so far. Since the objective of this article is to discern the applicability of different organization theories to certain SCM problems, this analysis is sufficient because the frameworks are introduced here over a broad scope of analysis and at a general level. Thus, they allow for integration of various different types of problems into the following analysis. From the preceding paragraphs, the following key elements of SCM can be summarized:

- supply chain structure, depending on the number of functions and businesses considered (internal, bilateral, chain and network),

- management components, depending on the degree of influence one company has upon the whole supply chain,
- business functions, providing for different types of links among partners in a supply chain.

This understanding of SCM will now be embedded into the theoretical debate on the applicability of certain theories to SCM research.

3 Organization Theories in SCM

This section is dedicated to the analysis of certain organization theories and their applicability to specific SCM problems and questions. In order to realize this analysis, a set of evaluation criteria needs to be identified which will then allow for the realization of the analysis. In accordance with the previously developed understanding of SCM, it can then be highlighted which organization theories focus on certain aspects of the overall SCM concept.

3.1 Criteria for analysis

In 1989, the Academy of Management Review, a highly recognized and internationally acknowledged journal, dedicated a special issue on what constitutes qualitative theory. Two of the articles comprised by this special issue from Whetten (1989) and Weick (1989) deal with the evaluation of theories. According to these two authors, the fundamental questions "*what*", "*how*", "*why*", "*who*", "*where*" and "*when*" give answers to all relevant elements a complete theory must refer to (Whetten, 1989, p. 490; Wacker, 1998, p. 366):

- *What*? The answer to this question comprises the factors (variables, constructs, concepts) that should be logically considered as part of the explanation of the social or individual phenomena of interest.
- *How*? This question provides an analysis of the relationships of the factors the theory is composed of.
- *Why*? This question serves to identify the underlying psychological, economic, or social dynamics that justify the selection of factors and the proposed causal relationships.
- *Who*? The answer to this question recognizes the main actors and their scope of manoeuvre (i.e. the degree of influence upon associated partners) attributed to them by the theory.
- *Where & when*? These conditions place temporal and contextual limitations on the propositions.

This set of criteria, as proposed by Weick and Whetten, has primarily been designed for the assessment and evaluation of empirical theories, i.e. theories that are composed of a limited number of variables which can be submitted to empirical tests leading to validation or falsification. However, the transferability of these questions to SCM and organization theory contexts is problematic since both areas are very complex and comprise a broad range of interconnected elements which cannot easily be separated from each other. In addition, there is neither just *one* theory of SCM nor *one* organization theory, but a large number of them. The high number of competing perceptions and theories is mainly due to the different pictures researchers within these fields draw of human beings and complex problems.

Therefore, we propose to alter and “soften” the five questions and make them more suitable for the investigation of complex problems such as SCM as follows: The rationale of “*why*” will refer to the objective SCM is supposed to pursue according to the theory. This can comprise the underlying sociological, psychological and economical reasons for the establishment of SCM. The answer to the question *"what"* will serve to identify the scope that SCM covers according to the theory, and accordingly describes the number and levels of companies involved in the supply chain as defined by Harland. The analysis of the question *"who"* will refer to the main actors, their scope of action and manoeuvre possibilities within the supply chain. Accordingly, this question deals with aspects of power and degree of influence upon associated supply chain partners. "*Where*" and "*when*" delimit the environmental context of the supply chains, both from a spatial and temporal perspective. Factors that have to be considered here need to take the number, diversity and frequency of changes in the supply chain's environment into account. Finally, "*how*" indicates if the theory can provide a basis for the deduction of specific recommendations for the implementation of SCM in practice, for example supply chain network design aspects as defined by Cooper, Lambert and Pagh (1997, 2000). The differences in the perception of these questions are depicted in table 1.

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Insert table 1 about here

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In the following sections, different organization theories will be presented and their transferability to a Supply Chain Management context will be assessed using these criteria.

3.2 The role of organization theories for SCM research

In general, the overall objective of organization theory is to propose optimal organization structures and designs that enable practitioners to model organizations so that tasks can be fulfilled in a most efficient and effective way. Thus, it is not surprising that organization theory is discussed more and more within SCM literature (e.g. Ketchen and Giunipero, 2004; Ketchen and Hult, 2006). A primary concern of SCM is to generate competitive advantage by increasing efficiency and effectiveness across companies. Therefore, the transfer of the organization theory body of literature to SCM mainly intends to analyze which forms and models of organizational structures seem to be the most successful in a supply chain context. The object of analysis is thus broadened from an individual organization perspective to an overall supply chain perspective. However, the organization theory literature is not coherent. Approaches vary according to the ontological, epistemological and methodological positions adopted by scientists which lead to varying results and propositions, depending on the point of view assumed. Thus the question arises whether some of these theories might be more suitable for the investigation of such complex problems as SCM than others.

In order to discern main streams within organization theory, various classifications of its main differences have been proposed. One of the most recognized classifications stems from Burrell and Morgan (1979) who classify four paradigms along the dimensions subjective vs. objective and order vs. radical change. The functionalist paradigm assumes rational human action and a reality that can be uncovered by scientific inquiry. Researchers within the interpretative paradigm assume that reality is socially constructed and dedicate their work to the observation of the process of social construction. Like the interpretative paradigm, the radical humanist paradigm emphasizes that reality is socially constructed but it tries to actively influence and modify the process of construction. Finally, the radical structuralist paradigm perceives reality as existing on its own account and tries to generate constant change (Morgan, 1980, pp. 608-609). Other classifications have been provided by Pfeffer (1989) and by Astley and Van de Ven (1983), who differentiate levels of analyses and scopes of manoeuvrability.

This short introduction to the theoretical and philosophical debate in organization theory highlights some of the main differences between the proposed organization theories. An awareness of these differences is essential for the following analysis. The perspective adopted by scientist of SCM needs to correspond with the perspective that is at the heart of the organization theory selected for investigation. Otherwise, the adoption of competing paradigms might lead the whole research process into a diffuse misconception.

Some of the most frequently cited organization theories (e.g. Kieser, 2002) include: contingency theory, new institution economics (comprising transaction cost theory, agency theory, and property rights theory), population ecology, network theory and institutionalist approaches to organization. Depending on the perspective adopted, game theory, resource-based view, market-based view and systems theory are classified as organization theories as well. We argue here that the latter set of theories are more concerned with decisions of strategic management and less with organizational structures, and therefore classify these as strategy theories which will be left for discussion elsewhere.

In the following paragraphs, each of these organization theories will be presented briefly. Their transferability to SCM will be discussed based on the set of criteria for analysis as defined previously. Finally, an overview of previous scientific applications of the respective theories to an SCM context will be given.

3.3 Contingency theory

Contingency theory of organizations mainly developed from fundamental criticism of Weber's model of ideal bureaucracy, since empirical studies lead to the conclusion that organization structures in reality rarely correspond to Weber's ideal type. These findings induced researchers to hypothesize that organization structures may vary according to the situation of their external environment as scientists became aware that general organization principles are not precise enough to be of assistance for practice. Accordingly, organizations need to adapt their structures to the respective situation in order to be efficient. Scientists within the contingency paradigm mainly rely on empirical analyses to investigate which organizational structures provide for the most efficient solutions in certain environmental settings. Based on these results, differences in organizational structures can be explained by deducing them to situational factors. In addition, they allow the prognosis of potential modifications in the organizational structure when a situation changes (e.g. Woodward, 1958, 1965). Finally, contingency theory provides for recommendations of organizational design, depending on an analysis of the environmental situation (Kieser, 2002, p. 169).

In addition to Joan Woodward, Burns and Stalker (1961) are recognized authors within the contingency theory paradigm. Their hypothesis: mechanical organization structures are more efficient in a static environment and organic structures are more efficient in a dynamic environment. Mechanic organization structures are characterized by detailed definition of narrow tasks, numerous hierarchical levels and formal rules, central decision making and broad differences in the formation and qualification of staff members in varying hierarchical levels. The characteristics of organic organization structures are the opposite.

While the aforementioned authors usually investigated one particular situational factor of the organization structure, a group of scientists following Derek Pugh from Ashton University, Birmingham, tried to consider various context variables, referred to as the "Ashton program". Examples of such contextual factors are the origin and history of an organization, its ownership and control structures, the company size in terms of number of employees, turnover, etc., company culture and values, applied technologies, location, material and human resources, and interdependence (e.g. Pugh et al., 1963; Pugh et al., 1968; Pugh et al., 1969).

Finally, Lawrence and Lorsch (Lawrence and Lorsch, 1969) hypothesize that different departments and business units within one organization need to be designed differently since they can be affected by varying environmental contexts. However, this also affects the mode of cooperation between different parts of an organization and makes coordination difficult. Therefore, coordinating units are required to assure the effective and efficient coordination between sub-units.

Contingency theory has been applied to SCM research by Stonebraker and Afifi (2004) who provide a categorization of four historical phases of supply chain development and classify distinct supply chain strategies that are appropriate for each environment. The authors then equate these historical phases of the supply chain emergence to processes, facilities, businesses and industries. In the end, it is posited that a successful supply chain integration effort depends on long-term, mid-term and short-term strategies and tactics that balance the differentiation of serial supply chain activities and the integrative effort applied. Furthermore, Rozemeijer, van Weele and Weggeman (2003) apply contingency theory in a buyer-supplier context and investigate how large corporations may effectively manage purchasing synergies among individual business units (primarily intra-company analysis).

The rationale of *what* refers to the scope an organization theory attributed to SCM. As the example from Lawrence and Lorsch illustrates, contingency reflections take into account the specific situations in the environment of departments and business units. Thus, it seems possible to apply the contingency ideas to diverse supply chain levels including internal, bilateral, chain and network relationships. Furthermore, contingency theory analyses can provide insights into the synthesis dimension of the 3S-model proposed by Giannakis and Croom, by enabling the investigation of a strategic position of the supply chain within a certain environment. Regarding the question of *why* SCM ought to be realized, contingency theory examines those organizational structures that best adapt to environmental challenges. Therefore, from a contingency theoretical perspective, SCM ought to be realized because the environment requires it. Thus, Christopher (1998, pp. 272-284) argues that SCM is a result of increased international competition that obliges firms to cooperate instead of compete. In this sense, contingency theory provides an explanation for SCM existence due to external pressure and the need to face external challenges by new organizational forms. Furthermore, it is supposed that SCM has to be implemented because the environment obliges companies to do so, thus the actor (i.e. the manager within a supply chain) only has limited scope of maneuver (*who*). Concerning the question of *how*, contingency theory is frequently criticized for insufficient refinement of statistical measures and its lack of comparability across studies (e.g. Kieser, 2002, pp. 183-191). Although it might be possible to deduce recommendations for supply chain design, these recommendations might be inconsistent. Furthermore, contingency theory is somehow a vague, abstract concept that often leads to contradictory results. This fact makes the deduction of recommendations even more difficult. Contingency theory is capable of comprising long-term periods of strategy formulation and implementation as well as continuous control with regard to temporal and spatial restrictions. In addition, there are no contextual limitations: the environment under investigation can be static, dynamic, highly competitive and so on. Accordingly, there are neither temporal nor spatial restrictions to contingency theory examinations of SCM (*where & when*).

3.4 Transaction Cost Economics

The primary objective of transaction cost economics (TCE) is to determine which types of transactions can be realized most effectively and efficiently in certain institutional arrangements. The transactions as well as the institutional arrangements may differ in certain cost-relevant characteristics. Actors within TCE are characterized by bounded rationality, opportunistic behavior and risk neutrality. Costs for transactions are influenced by three factors: the degree of specificity of a transaction, for example investments in assets, equipments, human capital, customer-specific investments, reputation (e.g. importance of brand name), and time (e.g. seasonal products); uncertainty about situational factors of transactions and their future developments, and the behavior of the contracting counterpart (opportunism); and the frequency of a transaction execution (economies of scale).

Based on these core assumptions, TCE provides recommendations for transaction contract design in specific institutional settings. Accordingly, for transactions characterized by a low degree of uncertainty and a low level of transaction-specific investments, a transaction can most effectively be executed via the market. With an increase in the degree of uncertainty and the level of transaction-specific investments, contract partners are forced to behave opportunistically in order to acquire above-normal rents. Therefore, a hybrid organization form is more appropriate which establishes obligations for information and sanction mechanisms via a contract. Finally, in the case of very high uncertainty and a very high level of transaction-specific investments, the transaction should be integrated into the organization to save costs for information procurement as well as contract negotiation and establishment (Williamson, 1975, 1991; Simon, 1959).

In a SCM context, TCE has experienced numerous applications. Ketchen and Hult (2006, p. 4) claim that TCE offers a “natural fit” with SCM. There is an increased tendency of organizations to outsource activities which implies that those companies whom organizations outsource to become supply chain partners. Since TCE is focused on the make or buy decision this theory has been frequently applied in SCM. However, TCE has not only been applied to outsourcing questions. Cohen, Ho, Ren and Terwiesch (2003) use a TCE framework to investigate the trade-off between shared forecasts and actual purchase orders in the semiconductor equipment supply chain. Hoyt and Huq (2000) investigate buyer-supplier relationships by means of several theories, transaction cost theory being one of them. At the center of interest for their research is the analysis of the role SCM relationships have for an organization’s ability to respond to dynamic and unpredictable change. Accordingly, they distinguish two major types of supply chain relationships:

- Competitive market/ low asset specificity: arms length relationships (limited investments in assets and minimal information exchange),
- Few suppliers/ high asset specificity: more formalized and less flexible supply chain design.

Skjoett-Larsen, Thernøe and Andresen (2003) examine the integration depth and scope of supply chain collaboration with a focus on collaborative planning, forecasting and replenishment as coordination mechanisms. Bharadwaj and Matsuno (2006) investigate how a vendor's order cycle, performance and trust can affect a customer firm's transaction costs, which in turn, affect customer-related outcomes, such as customer satisfaction and future purchase intentions. A last example is from Grover and

Malhorta (2003) who provide an analysis of the theoretical potential of transaction cost theory for SCM research.

TCE has a rather narrow focus of investigation since it is primarily designed for a detailed analysis of dyadic relationships. To a limited extent, this perspective can be broadened to a chain context, but anything going beyond a certain degree of complexity, for example a supply chain network, can only be modeled with substantial effort via TCE (*what*). The reasons for the implementation of SCM as deducted from TCE are rather restrictive, i.e. the primary objectives are profit maximization, cost reduction, efficiency, and effectiveness (*why*). According to the basic assumptions TCE predefines, the actors, i.e. the managers of the partnering organizations within a SCM context, have only a limited scope to maneuver: due to bounded rationality, simple profit maximization targets and the risk of opportunistic behavior because of diverging goals, the manager only has the possibility to search for the optimal transaction cost setting but not to directly influence and modify the institutional setting (*who*). Concerning recommendations for the implementation of SCM in practice, the above mentioned examples give a small overview of the possibilities in which TCE might be applied to. There are various institutional arrangements and questions that TCE might shed light on. However, it should be noted that capturing the overall costs incurred by one transaction, including long-term opportunity costs, is rather difficult. In addition, due to the restrictive picture of human beings, it is doubtful that findings via TCE are realistic (*how*). Therefore, we contend that, despite the broad applicability of TCE, it should be used in combination with other theories to compensate some of its weaknesses. Per definition, TCE takes into account ex-ante and ex-post transaction costs for the establishment of a transaction contract. Thus, despite the problem of cost predictability, there are no temporal restrictions to TCE. However, TCE calculations take place at one point in time and do not take into consideration the actual institutional setting.

Accordingly, the environment is mainly perceived as static. In case of a shift in environment settings, other TCE calculations will have to replace older ones (*where & when*).

3.5 Property Rights Theory

In essence, property rights theory analyses the effects different distributions of property rights have upon the behavior of actors and factor allocations, and explains the emergence, distribution and modification of property rights. Like TCE, property rights theory assumes that the economic actors strive for maximization of individual profit. In order to achieve their goals, the actors use scarce resources and are able to determine the contribution of different resources to the actors' net profit. In this context, institutional property rights determine who can use which resources and in which way. They vary according to different institutional settings. Four different types of property rights are distinguished:

1 Usus: to use,

2 Usus fructus: to retain yields,

3 Abusus: to modify,

4 Transfer: to transfer all rights, or parts of them, to others under concerted conditions.

In given institutional settings, actors will select those forms of property rights and establish those structures of property rights that maximize their net profit. It is hypothesized that the less property rights an actor has for a certain resource, the less net profit there is from the resource for the actor. Higher transaction costs for the determination, transfer and implementation of property rights of a resource lead to less net profit from the resource for the actor. Less property rights and rising transaction costs increase the probability for external effects and thus lead to suboptimal factor allocations (Demsetz, 1967, pp. 347-359; Alchian, 1965; Alchian and Demsetz, 1972).

Property rights theory has mainly been used to study the role and impact of different legal institutions on forms of property rights and their distribution between international supply chain partners (e.g. Longdin, 2005; Merges, 2005; Woodruff, 2004). Several other investigations focus on a specific type of property right, namely intellectual property rights, and their role within different industries (e.g. Tansey, 2002, Fernàndez-Bagüés, 2002) or in different countries (e.g. La Croix and Eby Konan, 2002). Evaluations of the contribution of property rights theory to SCM research and discussions of barriers that property rights might have when applied to SCM are very rare. The book of Longdin (2005) is an exception to this. Therefore, open research questions still remain and need to be discussed from the perspective of property rights theory within a SCM context.

In general, property rights theory examines property rights structure among two contracting parties. Therefore, it would usually be positioned at a dyadic level, according to the classification of Harland. However, it is possible to analyze property rights structures along a supply chain and even to apply the theory to smaller networks. Nevertheless, any application beyond dyadic relationships becomes rather complex and would, in most cases, be detrimental to accurate and detailed elaborations. Since property rights theory is primarily concerned with different types of property rights, it has some potential to contribute to the synthesis and synergy dimensions of the 3S-model proposed by Giannakis and Croom. On the other hand, the explanatory contribution to the third dimension: synchronization, is rather limited because this dimension is more or less concerned with the actual realization and design of property rights structures *after* their determination (*what*). At a first glance, property rights theory does not seem to give any clear reason why SCM ought to be realized but provides tools to assess which types of SCM-structures (and accordingly property rights structures) might be more efficient than others. This statement implicitly indicates a reason for the realization of SCM: Within certain contexts, it might be more (cost) efficient and effective to transfer property rights from one organization to another. In this sense, the target of SCM is to increase efficiency by establishing the most promising property rights structures among supply chain partners (*why*). According to the basic assumptions property rights theory predefines, the actors, i.e. the managers of the partnering organizations within an SCM context, have only a limited scope for maneuver. Due to bounded rationality, simple profit maximization targets and the risk of opportunistic behavior, the manager only has the possibility to search for the optimal property rights structures but not to directly influence and modify the institutional setting (*who*). The lack of conceptualization and operationalization make it difficult to deduce practical recommendations. However, in comparison to other theories which will be presented later, the scope of property rights theory is very narrow and limited to a certain object of investigation. An application to a specific SCM context and a detailed analysis of this situation will enable the deduction of specific recommendations (*how*). The time frame in which property rights theory is situated in is limited because of two reasons: Usually, property rights structures are analyzed ex-ante; once implemented, they will normally not be challenged or modified (e.g. outsourcing). The analysis is limited to a certain point in time and does not comprise long-term periods since costs for long-term property rights structures are very difficult to model. The contextual limitations are set by the object of property rights: resources. However, the theory does not cover any aspects of human interaction, questions of power, etc. and must, therefore, be considered as limited (*where & when*).

3.6 Agency Theory

Agency theory is concerned with situations in which one party (the principal) delegates authority to a second party (the agent) to act on his behalf (Eisenhardt, 1989, p. 57). The advantage of this arrangement is that the principal can authorize a specialized, experienced, well-informed and dedicated agent. However, the less information the principal has with regard to the motives, the actual performance and options of the agent, the higher the risk is that the agent does not behave in the best interest of the principal (Jensen and Meckling, 1976, pp. 78-85). Overall, agency theory is concerned with the solution of two problems: First, the agency problem arises when (a) the desires or goals of the principal and agent conflict and (b) it is difficult or expensive for the principal to verify what the agent is actually doing. Second, the problem of risk sharing which arises when the principal and the agent have different attitudes towards risk (Eisenhardt, 1989, p. 58). Three major agency problems are distinguished:

- Hidden information: information asymmetries before conclusion of a contract or after conclusion of a contract but before assuming work.
- Hidden action: information asymmetries after conclusion of a contract and after assuming work.
- Risk of shirking: information asymmetries to the principal's detriment and insufficient control mechanisms induce the agent to reduce his performance.

The agent disposes of three mechanisms to control the agent's behavior, namely *incentives* that stimulate the agent to strive for objectives that serve the principal as well (e.g. profit sharing), *control*, i.e. contractual stipulation of behavioral norms including sanctions, and *information systems* that increase transparency over the agent's scope of maneuver and therefore reduce possibilities for opportunistic behavior (Eisenhardt, 1989, p. 60; Arrow, 1985).

According to Eisenhardt (1989, pp. 59-63) and Jensen (1983, pp. 334-338), two major streams of agency theory can be distinguished. Positive *agency theory* is mainly descriptive and deals with the governance mechanisms for solving the agency problem. The normative *principal agent theory* is concerned with the general theory development of the principal-agent relationship and has a strong mathematical orientation.

Agency theory has been frequently applied for investigations into SCM. Zsidisin and Ellram (2003) apply agency theory to the analysis of buyer-supplier-relationships and study the effects of different variables, such as information systems, programmability, outcome uncertainty, outcome measures, risk aversion, relationship length and potential goal conflicts. Their findings illustrate that as supply risk sources become more prevalent, purchasing organizations are increasingly likely to implement behavior-based techniques that reduce information asymmetries, align organizational objectives, and program supplier activities. In addition, as the perceived risk increases, organizations are increasingly willing to invest in more intensive, behavior-based risk reduction techniques rather than simply focus on buffering the risk. Finally, outcome-based management, such as buffer techniques, fit in situations where it is not worthwhile for the purchasing organization to invest in changing the supplier’s behavior. Other applications include: the analysis of incentive provision, coordination costs and risk reduction within food marketing channels (Kuwornu et al., 2005); the understanding of business requirements for supply chain risk management from a practitioner perspective (Jüttner, 2005); a study on the impact of subcontractors upon supply chain management performance – analysis via agency theory (Wyanarczyk and Watson, 2005); and assessment of performance measurement and the optimal design of supply chains (Baiman, Fischer and Rajan, 2001).

Like property rights theory, agency theory is primarily designed for two party relationships and is, therefore, mostly applicable to the examination of dyadic relationships with a limited transferability to chain and network analyses. Via incentive, control, and information systems, agency theory has the potential to provide for new insights into all levels of the 3S-model proposed by Croom and Giannakis. For example, information systems impact the structure of supply chains and thus on the synthesis. Synergy is obtained via incentives and control contributes to synchronization of supply chain partners (*what*). From an agency theory perspective, the principal organization is obliged to contract with an agent since the organization is not capable of realizing the whole value creation for a product or service. The integration of associated firms is therefore used to decrease potential goal conflicts by implementing partnerships and gaining further control over associated partners. Overall, the objective is efficiency, effectiveness, cost reduction and profit maximization (*why*). Agency theory is based on the same core assumptions about human beings and behavior. Thus, a manager's motives and capacities are restricted and his manoervrability possibilities are determined by the described instruments for the solution of the agency problem (*who*). Agency theory has been criticized for its lack of conceptualization and operationalization (e.g. Ebers and Gotsch, 2002, pp. 221-224) which makes it difficult to deduce practical recommendations. In a certain, explicitly defined context, agency theory has the potential to make clear recommendations for practice (e.g. integrated information systems to cope with information asymmetries across the supply chain or concrete recommendations for interorganization supply risk management systems, as illustrated by Zsidisin and Ellram, 2003). However, without a clearly defined and narrow context, it is rather difficult to give clear recommendations for practice based on agency theory investigations (*how*). Agency theory is only focused on the ex-ante phase of contract establishment and does not explicitly consider long-term periods. Due to the slow momentum of analysis agency theory and the lack of long-term analyses, the environment is considered to be static (*where & when*).

3.7 Network Theory

The emergence of network theory owes much to the criticism new institution economics (NIE) has been confronted with. Within NIE, as we have just described, assumptions about the motives of economic actors are rather restricted. In addition, the main focus lies on the investigation of bilateral relationships. In addition to NIE, network theory takes into consideration numerous types of social and economic relationships, interconnected activities, and economic, personal and other motives.

The primary objective of network theory is to describe, explain and predict relations among linked entities (Thorelli, 1986). Many authors have contributed to the network theory body of literature and we will concentrate here on the concept of social embeddedness as proposed by Granovetter (1992), who emphasizes the social aspect of relationships which was neglected by NIE. Thus, the concept of embeddedness has the potential to compensate some of the weaknesses of NIE.

Granovetter assumes that "*the relevant agents are ultimately embedded in their society*" (Granovetter, 1985, p. 481). Accordingly, he investigates how economic action is embedded in structures and social relations, i.e. how economic relationships are structured by and depend upon social relationships. Such social relationships can exist between friends, business partners, etc. and are dependent on culture, religion, values and so on. They intertwine with business life. Granovetter distinguishes two different conceptions of human action. On the one hand, undersocialized conceptions neglect the social aspect of relationships, as classical and neoclassical economists do and see human beings as impeding objects. On the other hand, subsequent researchers have had the tendency to oversocialize their pictures of relationships. According to Granovetter, both approaches do not mirror reality as people neither act outside a social system nor are they totally influenced by social structures (Granovetter, 1985, p. 487).

According to Granovetter, the organizational structure of a network allows the establishment of the framework for social embeddedness. The structural form of a network is called “hybrid” as it can be integrated between the structural forms of market and hierarchy (Staber, 1999, p. 58). Whereas actors within a hierarchy are totally bound to organizational rules and regulations, actors in a market are totally free in their actions. A hybrid network form of organization includes both elements and mirrors human nature realistically: human beings wish to be free in their decisions but are embedded in social structures and rules that impede independent decision making. Based on these ideas, Granovetter comes to the conclusion that the structure of a network is able to serve as a skeleton for social embeddedness since it neither enforces undersocialized nor oversocialized patterns (Granovetter, 1985, pp. 493-504).

Network theory has been frequently applied to SCM research since Harland established the notion of supply networks as a special form of SCM in 1994. In the special issue of the Journal of Operations Management dedicated to the application of organization theories to SCM, two articles use a network theory approach. Morgan, Kaleka and Gooner (2006) apply network theory in combination with transaction cost economics and agency theory to investigate the antecedents and consequences of category-level focal supplier opportunism. Their findings suggest that with increasing influence of suppliers in the retailer’s category management efforts, they are more likely to adopt opportunistic behavior. In addition, the retailers’ ability to monitor opportunistic behavior of suppliers is negatively associated with the degree of opportunistic behavior exposed by these suppliers. The second article stems from McCarter and Northcraft (2006). They analyze the implications of viewing supply chains as social dilemmas, i.e. as a tradeoff decision between following their own interests or the collective interest of all members in the supply chain.

In general, the theory of social embeddedness analyzes the influence of social relationships on organizational structures, especially network forms of organization. Granovetter focuses on the exchange of information on different relationship levels, whereas the exchange of goods and services are of minor importance. In this sense, the network concept can be applied to the investigation of bilateral relationships and whole networks of interconnected businesses (*what*). Granovetter discusses the importance of social relationships. From his perspective, social influences on economic action were either overestimated or underestimated in previous research. Therefore, he focuses on the underlying social dynamics within networks and their impacts. While he neglects psychological aspects, economic dynamics are considered by extending existing approaches, such as NIE, to the theory of social embeddedness (*why*). According to network theory and the social embeddedness approach in particular, managers are informed to take social aspects into account. These managers are seen as capable of understanding the motives of partners and are assumed to be able to take advantage of this knowledge by actively influencing and shaping their environments. However, the entire consideration of all social relationships existing in a network can become so complex that the theory of social embeddedness rather helps to understand their interaction than to use them for supply chain optimization. Thus, the social embeddedness approach to networks helps to explain network structures. But it is difficult to deduce specific recommendations for optimal supply network design structures and processes. Granovetter approaches his analysis by discussing shortcomings of the transaction cost theory by Williamson. He does not question the importance of transaction costs for economic decisions, but rather links those costs to social relationships. Hence, he argues that social relations have non-negligible influences on the height of transaction costs and, thus, must be regarded when making economic decisions. However, Granovetter's approach remains vague and abstract and it is rather difficult to deduce any more specific recommendations from his theory of social embeddedness (*how*). Within the theory of social embeddedness, all actors such as companies, people, associations and other social groups are identified and included in a comprehensive analysis. As their behavior and interaction is the scope of the theory, their range of maneuverability is discussed in depth. This discussion can be easily transferred to supply chain management. However, it remains difficult to detect the informal main actors in complex network structures (*who*). The theory of social embeddedness takes into account numerous types of social relationships and their alterations over time. Furthermore, the theory asserts the modifications these social relationships experience when a certain decision is taken. Accordingly, there is no spatial limitation. Concerning restrictions of time, the theory has the potential to consider both short-term and long-term aspects of social interaction. Accordingly, there aren't any time restrictions either (*where & when*).

3.8 Institutionalist approaches to organizations

Institutionalists suppose that organization structures are designed according to the expectations and requirements of the environment, and not to the requirements their tasks and activities demand. Structural elements which are expected by society are adopted to legitimate organizational structures. Thus, changes within the formal structure of organizations are less and less determined by competition and requirements for efficiency, but by rules, requirements and expectations society has towards organizations. In the terminology of institutionalists, institutions are regularly reproduced activities. Regarding institutionalization, three different meanings of the term are differentiated

- Institutionalization as a process: The procedure by which social relationships and activities become integral parts of a situation and are not questioned further.
- Institutionalization as a state: The situation within which shared perceptions of reality determine what is important and what has to be done.
- Total institutionalization: The complete absence of any reflexive and intentional dimension of human actions.

From an institution theory perspective, organizations adopt structural elements because of their legitimacy and not because of their effectiveness. These institutionalized rules define new organizational situations, redefine existing ones and determine the means to handle them efficiently. The adoption of structural elements by organizations leads to an increase in the legitimacy of these elements *and* of the organization. Organizations that incorporate legitimated elements, are considered as rational by society. This acknowledgement increases their access to resources, thus leading to better conditions for their survival.

DiMaggio and Powell (1983, p. 149) developed the concept of isomorphism, defined as a constraining process that forces one unit in a population to resemble other units which face the same set of environmental conditions. Three driving forces support isomorphism. First, coercive isomorphism which results from both formal and informal pressures exerted on organizations by other organizations. They are dependent on cultural expectations in the society in which organizations function, for example the legal environment (governance or contract law). In addition, the expansion of the central state, the centralization of capital, and the coordination of philanthropy are factors which support the homogenization of organizational models through direct authority relationships. Second, mimetic processes which result from uncertainty. When an organization faces a problem with ambiguous causes or unclear solutions, a problematic search may yield a viable solution with little expense. Homogeneity in organizational structures can also stem from the fact that despite considerable search for multiplicity, there is relatively limited variation to select from. Finally, organizations tend to reproduce themselves according to similar organizations in their field which they perceive to be more legitimate or successful than themselves. Third, normative pressures support isomorphism. They stem primarily from professionalization – the collective effort of members of an occupation to define the conditions and methods of their work, to control "the production of producers" and to establish a cognitive base and legitimation for their own occupational autonomy. Normative pressures are either the result of formal education produced by university specialists or of the previously described efforts of professional networks (DiMaggio and Powell, 1983, pp. 150-154).

There are some applications of institutional thinking within SCM research, but they are not numerous. Connolly et al. (2005, p. 157) depict only one element of institutionalism and state "*the more interdependent the participants in a supply chain become, the more isomorphic their organizational structures will become*." However, this aspect is not developed further in the following investigations. Bianchi and Ostale (2005) utilize an institutional perspective to examine unsuccessful internationalization efforts. From their perspective, retailers are more likely to succeed when they adopt their retail formats to the norms of the local market and achieve legitimacy from the relevant social actors. However, only case studies of failures are integrated in their analysis. Thus, it can only be supposed that a stronger integration into local structures would have led to success. Since no success has been investigated, this remains pure speculation. From the perspective of Rogers et al. (2006) who use institutional theory for their investigation, industry recipes are used to inform but not dictate supply chain management activities. Finally, Lai, Wong and Cheng (2006) examine the adoption of information technology along supply chains from an institutional pressure perspective.

An application of institutionalist approaches to supply chain management is not restricted to any level of analysis: the impact of legitimated, institutional elements and their adoption to dyadic relationships, chains and networks can be investigated. Furthermore, it might be possible and even of great interest to analyze SCM as an institution: Is SCM a paradigm/institution that obliges other companies to adapt SCM policies and strategies as well without considering the success potential for SCM practices (*what*)? Interestingly, interpretations of the why dimension can be twofold. From a macro perspective, organizations apply SCM because the environment requires it (deterministic influence of the environment). From a micro perspective, the successful application of SCM by one organization would have induced other organizations to follow, which would then establish SCM as a paradigm (voluntary). In either case, SCM can be considered a rational, legitimated structural element that should be applied by organizations in order to gain access to resources (*why*). As for the why-dimension, two interpretations are possible for the *who* dimension. However, institutionalist approaches to organization strongly emphasize environmental impacts upon organizational design. Accordingly, we assume that the scope of maneuver attributed to managers is restricted (*who*). Within the institutionalist paradigm, recommendations for practice are strongly dependent on the environmental situation of a specific supply chain under investigation. In this sense, the potential for recommendations is dependent on the problem defined and the supply chain partner organizations. To summarize, institutionalism has only limited potential to give concrete recommendations for SCM design (*how*). Changes within society and that which is considered legitimate or not are supposed to evolve slowly over time (long-term processes of institutionalization). This leads to the conclusion that the process of inducing institutional change is limited to long-term operations. Environmental conditions can be analyzed across regions, industries and nations. Thus, there are no spatial limits to the scope of analysis.

3.9 Population Ecology

Similar to institutionalism, population ecology assumes that organizations are far too complex to be transformed into a specific shape by means of planned intervention. Unlike institutionalism, researchers of the population ecology paradigm borrow ideas from biology and Darwin’s theory of survival of the fittest. Thus, it is not the organization design but the selection of the environment which decides about the usefulness of organizational variations and their survival. Three reasons explain why organizations only have a limited ability to directly adapt to changing environmental conditions. First, the members of one organization strive for very different interests. Hence, organizational outcomes depend heavily on internal politics and on the balance of power among the constituencies. Outcomes cannot easily be matched rationally to changing environments. Second, there is a certain degree of uncertainty about means-ends connections. Carefully designed adaptations may have completely unexpected consequences and short-run consequences may often differ greatly from long-run consequences. Third, structural inertia impede learning and adjusting structures to compensate for the temporal patterns of relevant environments (Hannan and Freeman, 1984, pp. 149-151).

Within population ecology, the unit of analysis is the population composed of a community of organizations. Certain organizations are supposed to belong to the same population when they adopt the same common principles of organization (blueprint), i.e. the same rules and procedures for obtaining and acting upon inputs in order to produce an organizational product or response. Structural inertia separate populations of organizations from each other: The stronger the pressures, the lower the organizations' adaptive flexibility and the more likely that the logic of environmental selection is appropriate. Such structural inertia can be either internal to organizations (for example investments in plant, equipment and specialized personnel, incomplete information inputs, internal political constraints, path dependence) or external (for example legal and fiscal barriers to enter and exit markets, expensive acquisition of external information about relevant environments, legitimacy constraints). Evolutionary processes are induced by variations or innovations, i.e. one organization successfully implements a modification or innovation or one organization arrives at imitating another successful organization. These variations are at the core of the process of natural selection and provoke less efficient organizations to succumb in the struggle for existence. Finally, organizations need to be capable of conserving selected variants and to transfer them to other organizations. This process is called reproduction (Hannan and Freeman, 1984, pp. 151-155; Hannan and Freeman, 1977, pp. 933-938).

Population ecology has only been applied to a very limited degree to SCM research. One study stems from Venkatasubramanian et al. (2004), who present a theory of self-organization by evolutionary adaptation and show how the structure and organization of a network is related to its survival and performance. According to the authors, a complex system optimizes its network structure in order to maximize its overall survival fitness which is composed of long-term and short-term survival components. The survival components depend on critical measures of the network: efficiency, robustness, cost and environmental selection pressure. Fitness maximization is obtained by adaptation and leads to the spontaneous emergence of optimal network structures of various topologies depending on the selection process.

In population ecology, the unit of analysis is not restricted to and primarily designed for single organizations but for whole populations of organizations. Therefore, the theory seems to be predestined for an application for SCM analyses for internal, dyadic, chain or network investigations. However, the population, i.e. the members of the supply chain to be analyzed, need to be defined by a common blueprint (“gene pool”). This blueprint can cause problems because blueprints are usually defined for organizations that belong to the same industry, whereas supply chain partners can belong to various industries. Population ecology approaches to SCM can provide new insights into the synthesis and synergy dimensions of the 3S model by Giannakis and Croom (*what*). According to population ecology, the reason for the application of SCM practices is rather simple: survival. Pressures in the environment oblige companies to strive for different organizational forms which seem to be more promising within the struggle for existence. Supply chain practices could be such a form of organizational design and their success would justify broader application within organizations belonging to a similar environmental setting (*why*). The decision maker’s scope of maneuver in a supply chain is entirely determined by environmental pressures and is therefore limited (*who*). Recommendations for practice are strongly dependent upon the environmental situation of the specific supply chain under investigation. The potential for recommendations is dependent on the problem defined and the supply chain partner organizations being considered. Within these clearly determined situations, the recommendations are rather concrete (*how*). Finally, both long-term and short-term orientations are possible with population ecology, depending on the dynamics of the environment. Usually, the analysis is restricted to populations of organizations defined by a blueprint. Therefore, some problems might occur within a broader SCM context that strives to investigate whole supply networks from the raw materials supplier to the end-customer. Blueprints would have to be defined as all those companies that belong to the same supply chain and face the *same* environment, which might be a problem (*where & when*).

4 Summary and conclusions

In the previous paragraphs, an assessment of the applicability of organization theories, namely contingency theory, transaction cost economics, property rights theory, agency theory, network theory, institutionalism and population ecology, to Supply Chain Management research was realized. For each of these theories, the fundamental questions as to *what*, *who*, *how*, *why*, *where* and *when* were answered. As a result, a classification of the theories is proposed which enables researchers within SCM to assert open research questions and to identify theories that might be suitable for their problem under investigation. In addition, although the overview of articles presented for applying certain theories to a SCM context is not exhaustive, it has become clear that transaction cost theory, network theory and contingency theory have been frequently applied to investigate SCM research questions. Other theories, including population ecology, institutionalism and property rights theory, are not applied very often. Such investigations might provide for interesting new insights into SCM and therefore constitute an interesting research direction for the future.

The answers to the questions for each theory presented in the previous sections are summarized in Table 2:

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Insert table 2 about here

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These findings can now be compared in more detail with the understanding of SCM as it has been developed in the literature review. There, it has been contended that SCM is a result of increased global competition, the need for organizations to find new ways to survive and to gain competitive advantage. To further assure comparability of our findings, the following classification of the why-dimension is proposed: theories suggesting only one objective (e.g. mere survival) only offer a small contribution for further investigations of SCM. Those theories that add another objective to the one of survival - which we consider as being automatically implied in any other target - are classified as having medium potential. Finally, theories exceeding two targets - as for example network theory which includes survival, economic and social targets - offer a high potential for future research.

With regard to the scope SCM research is able to cover when applying a certain theory, we assume that those theories which capture only internal and dyadic relationships incorporate a small potential. Among the theories presented here, these are transaction cost economics, agency theory and property rights theory. Those theories which can be extended to a chain level have medium potential. None of the above presented theories can be subsumed in this category. A large potential for future research is exposed by those theories that can be applied to the investigation of internal, dyadic, chain and network problems of SCM. In the present analysis, these are contingency theory, network theory and institutionalism. In principle, population ecology ought to be classified as having a large potential as well. However, due to the substantial problem of defining all companies belonging to the same supply chain or network as one population by means of a blueprint, we will attribute only medium potential to population ecology.

One of the fundamental ideas behind SCM is that managers can extend their scope of maneuver beyond their own organization to associated members of a supply chain. Thus, the performance of all members will increase if they align their business processes, reduce delivery times, decrease inventories, etc. This involves an alignment of strategies among supply chain partners. The premise behind these arguments is that managers have a certain degree of influence and potential to proactively design and influence other organizations belonging to the same supply chain. Of course, the degree of influence varies according to the size and importance of the company under investigation within the whole supply chain. Therefore, we propose that those theories which portray managers mainly determined by the environment and only have a limited manoeuvrable scope, offer little potential for further investigations in this area. They are mainly applicable to the weakest companies in a supply chain, as is the case for contingency theory, transaction cost economics, property rights theory and population ecology. Lastly, network theory does not limit the scope of maneuver of the decision maker per se, but advises him to take numerous types of relationships into consideration which will be impacted by his decisions. From an agency and institutionalism perspective, the manager has scope of maneuver, but it is restricted: In agency theory, he can decide who to assign as agent and which control, incentive and monitoring devices to use. In institutionalism, most parts of organizational design are the result of expectations from society towards legitimate organizational structures. However, these expectations do not exceed a certain institutional level and decision makers still can decide on the concrete form. In sum, we suggest that theories which limit decision makers scope of maneuver to pure reaction to environmental pressures, do not offer great potential for further investigation in SCM. Those theories which assign a certain scope of maneuver have medium and those which do not restrict the scope offer a high degree of future research potential.

Some of the theories presented in the previous sections are rather abstract, for example network theory, population ecology and institutionalism. It is difficult to apply these theories to specific problems, to analyze these empirically and to deduce general recommendations from these theories. Rather, they should be used in case studies and other qualitative research methods to assess a very specific problem and to explain the specific problems from the respective theoretical view. Other theories, such as those belonging to NIE and contingency theory are designed for specific situations and provide direct application guidelines. We propose that those theories, whose general recommendations can only be derived with difficulties, have a high potential for future research. Numerous investigations in the form of case studies can be performed with these in the future. On the other hand, NIE approaches and contingency theory are already very concrete per nature but can be further refined. Therefore, we assume that their potential for future research is medium.

Lastly, for many companies, the implementation of SCM practices, inter-organizational integration and the establishment of partnerships does not make sense if these were only to last shortly. In general, SCM's intention is to establish long-lasting partnerships to be able to jointly generate competitive advantage in highly competitive markets. Thus, research within SCM should take the dynamics of environmental settings and the requirement for long-term orientation into consideration. Again, those theories which delimit both the spatial and temporal context only offer a limited potential for future SCM research. This is the case for transaction cost economics, property rights theory and agency theory. Contingency theory, network theory and institutionalism are neither restricted with regard to time nor with regard to space. Finally, analyses via population ecology are mainly long-term oriented and have only limited applicability in short-term investigations. Therefore, population ecology is classified as having medium potential for future research.

These reflections are depicted in Figure 1:

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Insert figure 1 about here

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Since the proposed framework has been developed on the basis of a literature review, the reflections presented in this article and the proposed framework should be further validated by means of empirical investigations and analyses.

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Table 1: Overview of assessment questions for the evaluation of theories

Question	**Traditional**	**Transferred to SCM**
Why?	Identifies the underlying psychological, economic, or social dynamics that justify the selection of factors and the proposed causal relationships	Defines the objective SCM is supposed to purse according to the theory including psychological, economic and social dynamics
What?	Comprises the factors (variables, constructs, concepts) that logically should be considered as part of the explanation of the social or individual phenomena of interest	Identifies the scope that SCM covers according to the theory (e.g. internal, dyadic, chain or network)
Who?	Recognizes the main actors and their scope of manoeuvre	Refers to the main actors and their scope for manoeuvre within the overall supply chain
How?	Provides for an analysis of the relationships of the factors, the theory is composed of	Indicates if the theory can provide a basis for the deduction of specific recommendation for the realization implementation of SCM activities in practice
Where & when?	Place the temporal and contextual limitations on the propositions	Delimit the environmental context a supply chain is situated in

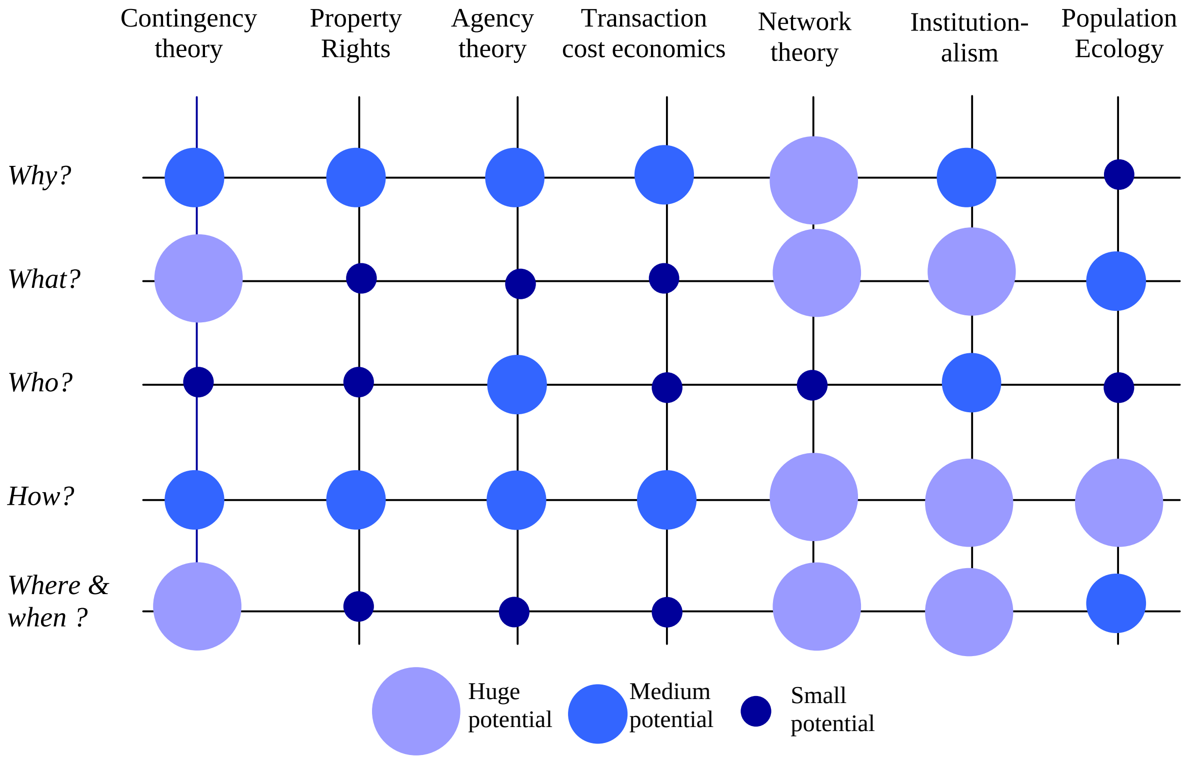
Source: Own illustration

Table 2: Evaluation of organization theories for SCM research - overview

	Obje-ctive (*why*?)	**SCM scope** (*what*?)	**Scope of maneuver** (*who*?)	**Environment of SCM context** (*where & when*?)	**Recommendations?** (*how*?)
Contingency theory	Above normal rents	Dyadic, chain network	Determined by environment	Static & dynamic	Concrete but risk of inconsistency
Transaction cost economics	Above normal rents	Dyadic, (chain)	Determined by environment	Static	Concrete in specific situations
Property rights theory	Above normal rents	Dyadic, (chain)	Determined by environment	Static	Concrete in specific situations
Agency theory	Above normal rents	Dyadic, (chain)	Mixture of voluntary and determined by environment	Static	Concrete in specific situations
Network theory	Economic and social motives	Dyadic, chain, network	Mixture of voluntary and determined by environment	Dynamic	Difficult to deduce
Institutionalist approaches	Legitimation	Dyadic, chain, network	Determined by environment	Dynamic	Difficult to deduce
Population ecology	Survival	Defined by blueprint	Determined by environment	Dynamic	Concrete

Source: own illustration

Figure 1: Potentials for future research



Source: own illustration

KNOWLEDGE MANAGEMENT IN SCM WITH INSTITUTIONAL PERSPECTIVE

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ABSTRACT

Institutional perspective lets the traditional supply chain management become a new competitive strategy. The major reason is that problems of supply chain management are not only existed in external supply chain from suppliers of upstream to manufacturers, distributors and retailers of downstream, but also usually existed in internal supply-chain organization. Transferring best practices of external supply-chain into the internal supply-chain organizational learning also become an important institutional factor. However, rarely researches discuss on relationships between external and internal supply-chain. Therefore, based on our practical consulting experiences we propose a framework of SC-KM learning which organizations can use to assist business in integrating external and internal supply chain with institutional perspective. The framework contents four practice-research levels, including analysis and descriptions of external and internal supply chain, knowledge management processes- creation, storage, sharing, transferring, and application-, and performance measurement.

INTRODUCTION

Supply chain management (SCM) was a very complex and cross-level issue for an enterprise, because its problems implicate upstream and downstream of enterprise external supply chain, even including each department of enterprise internal supply chain from R&D, production and manufacturing, distribution, sales and marketing, human resource, financial and to accounting (Lo, Hong, Jeng, & Liu, 2006).

Enterprise internal supply chain also comprises different business processes, and these business processes were cross-level operations on organizational and institutional framework, and accompanied business core knowledge at the same time, thus, employee to be knowledge workers were based on this framework and standard operation processes (SOP) with knowledge to complete the goals of departments and organizations.

Therefore, a successful organization with institutional perspective was contenting internal and external enterprise organizational learning mechanisms. These mechanism let organization managers understand how to accomplish organization continued learning and mimetic capabilities through other enterprises successful experiences.

Jr. and Giunipero (2004) thought institutional theory was one theory of strategy management, and the organization of enterprise through mimetic processes can learn supply chain best practices; therefore, supply chain of enterprise can increase more competitive advantages and become supply chain organization.

Bello *et al.* (2004) thought that the institutional arrangements refer to rules of exchange and consist of contracting, ownership, and social elements that will affect organizational cooperation and supply chain innovation.

Miles and Snow (2006) found different theoretical perspectives related to researches of supply chains including strategic choice, resource-based view, and knowledge management. Moreover, supply chain was viewed a network organization, through knowledge sharing and application of internal and external networks approach common goals and cooperation.

Christensen *et al.* (2005) also consider about the supply chain with different knowledge from suppliers of upstream and customers of downstream. Suppliers' supply chain knowledge and customers' supply chain knowledge can thus directly affect market performance with Just-in-time (JIT) strategy and Build-to-order (BTO) strategy.

Therefore, from above mentions, we find that institutional perspective in supply-chain organization is not only one kind of constrains, but also one kind of resource or strategy. Because, organizational managers learn and implement methods of supply chain best practices into business processes, and these business processes affect users or employees' behaviours. Then, during exchanges of information and communication at the same time, new knowledge learning and application was performed, thus, enterprise became a learning-style organization.

However, rarely researches discuss relationships between external and internal supply-chain knowledge management with institutional perspective in recently years. Because the complex and cross-level problems of internal and external supply chain, we need to consider strategic management, organizational learning, knowledge management processes, and knowledge management system. Thus, how to integrate views of practice and research in order to observe a supply chain learning organization became a new challenge.

In this paper, we construct a practice-research framework for a SC-KM learning organization with institutional perspective. The framework consists of four practice-research levels which are including analysis and descriptions of external and internal supply chain, knowledge management processes (creation, storage, sharing and transferring, applications), and performance measurement. The purpose in this paper to design a framework considered strategic management, organizational learning, knowledge management processes, and knowledge management system with an institutional perspective in internal supply chain management.

The rest of the paper is organized as follows. Next section describes the relationships between institutional and organization learning, and then to describe knowledge management how applying to supply chain management, therefore, based on our practical consulting experiences we provide a framework for SC-KM learning organization, finally, we give the integrated conclusion.

INSTITUTIONAL PERSPECTIVE AND ORGANIZATIONAL LEARNING

In recently years, some theories of strategic management such as agency theory, strategic choice theory, and institutional theory have been applied into research fields of supply chain management. These new trends of research fields integrated the strategic management and supply chain management, and those thought supply chain management as one part of strategic management, even these researchers also thought supply chain should became a supply chain organization. Therefore, how to integrate capabilities of internal and external organization became an important research issue and challenge, and one important part was institutional perspective existed in supply chain.

Jr. and Giunipero (2004), Jr. and Hult (2006) thought strategic management and supply chain management have overlapping interests. Their researches found that supply chain needed to be a supply chain organization, and the organization needed to consider strategic management with institutional perspective into supply chain management.

In addition to this, Jr. and Hult (2006) also proposed their another view in organization theory and supply chain management with institutional perspective. They thought traditional supply chains rely heavily on industry recipes and best practices to "guide" supply chain management activities. However, compare with best value supply chains with institutional theory was different on "informing" and not dictate supply chain management activities.

Institutional perspective affects not only organizational knowledge transfer with learning and mimesis, but also organizational administration performance. Madanmohan (2005) used the method of case study to find the impact factors of successful e-marketplaces with institutional perspective. Those can directly affect the organizational performances including ownership and bias, service focus, value impact, market opaqueness, rapidity of response, complementary assets and appropriability, and industry regulation emerge.

Raisinghani and Meade(2005) developed a analytic-network-process framework to measure organizational performance; this framework consists of four levels-organization performance criteria, dimensions of agility, dimensions of costs in supply chain management, dimensions of knowledge management. Cost, time flexibility, and quality were organizational performance criteria; the impact dimensions of agility were leverage people and information, master change and uncertainty, collaborative relationship, and enrich customer; dimensions of costs in supply chain management were including costs of information, inventory, facility, transportation; finally in dimensions of knowledge management were creation, storage/retrieval, transfer, and application in knowledge management processes.

On the other hand, institutional perspective also leads information system to become one reason of smoothing organization operation. Kakihara and Sorensen (2002) used two case studies exploring knowledge emergence to find out that information system was part of information and communication technology(ICT), and information system in particular plays an important role in knowledge management practices. That is, information system can thus assist organizational operations more efficient and effective. However, they especially emphasized that institutional perspective can shape managers' strategic decision-making processes and hence the organizational form of firms. It can supersede information system as tools for efficient and effective operation in supply-chain organization.

Usually, internal knowledge was created by organizational employee because the business processes were related to each department of internal organization interaction. Thus, managers also are knowledge workers due to their conducting projects or routines in today. Bello *et al.* (2004) thought organizational employee methods of learning and innovations in-deep affected from internal organizational regulatory, normative, and cultural-cognitive of institutional environment.

Bates and Slack (1998) thought that knowledge existed between relationships of customers and suppliers of supply chain, and the suppliers usually created knowledge and interactions from pressures of customers. Therefore, these pressures of customers became organizational internal pressures of learning and capability. In their observations, knowledge exchanges especially concern manufacturing processes (internal knowledge) more than market knowledge (external knowledge).

Because knowledge existed among customers and suppliers of supply chain, and then the knowledge of supply-chain processes also obtained by using organizational learning. In their study of innovation, market orientation, and organizational learning, Hurley and Hult (1998) found that organizational culture of learning was associated with organization innovativeness degree to impact capability of innovation, and therefore became competitive advantage and performance.

In addition, Hult (1998) thought market-driven organizational learning was a function of two concepts, including (1) the process of organizational learning and (2) the structure of the learning organization. Moreover, his research found that market-driven organizational learning in strategic sourcing units influence customer satisfaction, relationship commitment, and cycle time of the sourcing process.

Hult *et al*. (2000) found organizational learning has a positive effect on information processing in purchasing system, which also in turn, has a positive influence on cycle time of the purchasing process. In their research, they also found that organizational learning in the purchasing process is influenced by organizational culture factors of localness, transformational leadership, and openness.

Hult *et al.*(2003) considered the potential role of organizational learning as a strategic resource in supply management. In their study, they viewed organizational learning as a composite construct arising from four tangible indicators that were orientations of team, learning, system, and memory. They also found organizational learning has a positive effect on a set of learning consequences, supply management consequences, and performance consequences.

Therefore, we integrate different researches and found that the institutional perspective was associated with organizational learning of internal and external supply chain management. Figure 1 shows the relationship of strategic management and supply chain management.

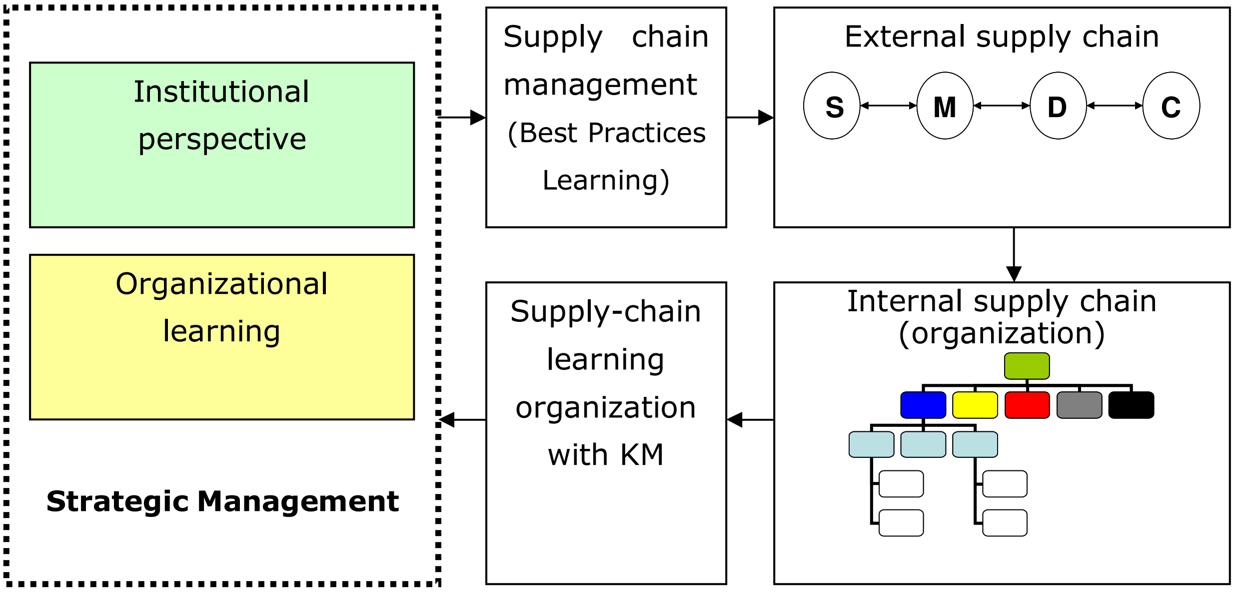

Fig. 1. Relationship between strategic management and supply chain management

KNOWLEDGE MANAGEMENT IN SCM

In Figure 1, we can found that the strategic management includes institutional perspective and organizational learning, and the supply chain management was influenced by strategic management for learning best supply-chain practices or best value supply chain to be a new competitive advantage. Thus the competitive pressures from external supply chain- suppliers, manufacturers, distributors, and customers- to internal supply chain- organizational departments: R&D, production and manufacturing, distribution, sales and marketing, human resource, financial and accounting- will feedback to push supply-chain-learning and then improve both aspects of strategic managements.

Based on the institutional perspective and organizational learning, organizational and personal knowledge were created and formulated into knowledge management system (KMS) to store, and then the knowledge was sharing and applying through organization internal or external networks. Therefore the knowledge management processes was performed in internal supply-chain organizational learning. Indeed, the consequences of internal supply-chain organizational learning with KM finally will influence to strategic management of enterprises.

To conclude, we thought integration of knowledge management was very important for organizational learning in a supply chain. Magnusson and Gothenburg (2003) thought that supply chain of small and medium-sized enterprises suck as network organization (separate juridical entities), and through a purposeful cooperation obtains knowledge integration. Thus, in their research through interviews and questionnaires in European found different network styles of supply chain with different degree on knowledge integration; and the network taxonomy thus divided into three network styles including supply-chain network (low degree of knowledge integration), business network (medium degree of knowledge integration), and research network (high degree of knowledge integration).

On the other hand, knowledge management can let the domain knowledge of business process become an improved capability for customer services and be a strategic resource in supply chain management at the same time. Hult *et al*. (2003) examined their assumptions; and the result of investigation found the knowledge can be a key strategic resource in logistics and purchasing order fulfilment processes. They also indicated that when knowledge was a key competitive advantage, the supply chain members' through learning processes would enhance their skills and knowledge, and then increase their capabilities of responding customers' products needs on speed, quality, cost, and flexibility.

Hult *et al.*(2006) also examined their notion that knowledge can be a strategic resource in supply chains. In their study found that eight elements of knowledge (memory, tacitness of knowledge, accessibility of knowledge, quality of knowledge, knowledge use, knowledge intensity, responsiveness, learning capability) were associated with supply chain performance (speed, quality, cost, flexibility, size of employees, age or year of enterprise), and also related to different strategic types (prospectors, analyzer, low-cost defenders, differentiated defenders, reactors). Hult *et al.*(2004) also had similar study on knowledge development processes and cycle time in strategic supply chain.

Indeed, knowledge management in supply chain management is not only to pressure organization internal learning, but also to provide a knowledge-based competitive method. Lang (2001) thought that knowledge-based competition contents pressures of globalization (liberalization, deregulation, privatization) and digitization/connectivity (infocom and Internet technologies). It then became new management imperatives in harnessing employee competencies (knowledge management), harnessing supplier competencies (value chain management), and harnessing customer competencies (customer value creation), and finally outcome to a sustainable competitive advantage.

Today, the industry becomes a new economics knowledge-intensive industry instead of production economics because of knowledge economics. McGee and Bonnici (2002) thought that global markets have grown. Knowledge supply and demand became extremely important because dynamics of network externalities create new situations for traditional industrial economics. This situation let knowledge be not enough and need to acquire new knowledge from outside, thus, the organization needs deconstruction value chain to analyze where were the significant knowledge components, and then reconstruct the value chain and deploy knowledge in supply chain.

Shaw *et al*. (2003) used a case study to explain that an organization must possess and share knowledge about the different facets of the supply chain to achieve success at supply chain management. In their study found that use KM through KM system can enhance the ordering process for service parts. Hart (2004) thus thought the supply chain with KM can become the "wise" supply chain, because it increases market share and maintains a competitive product depending on the ability of each unit in the chain to apply knowledge innovatively.

To sum up, we integrate different researches that have found the knowledge management associated with supply chain management as a key strategic resource, advantage, method, and create a new knowledge-intensive economics. Figure 2 was shown the relationship between knowledge management and supply chain management.

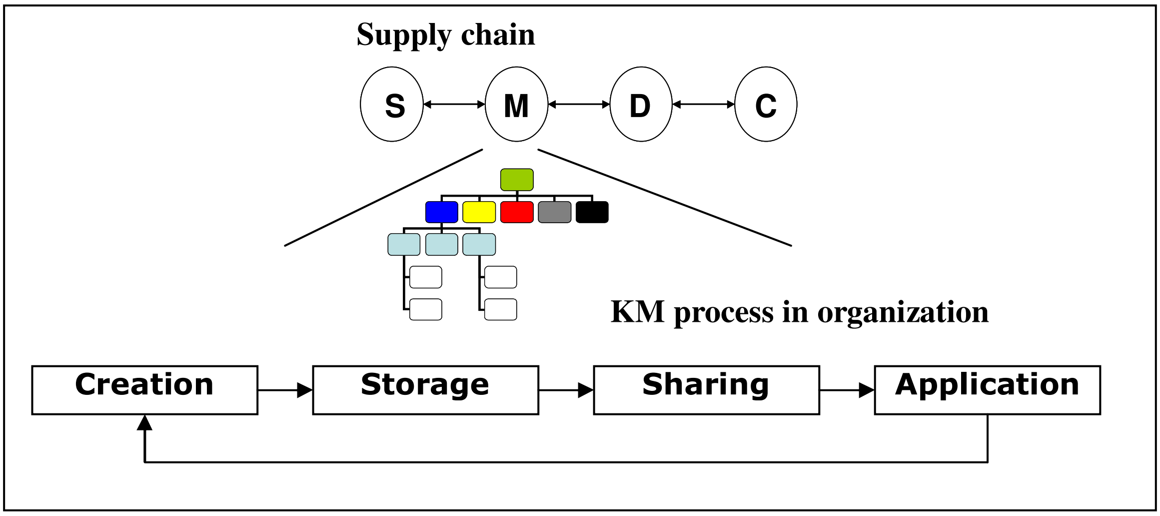

Fig. 2. Relationship between KM and SCM

In figure 2, we can find that organizational (explicit knowledge) and personal (implicit knowledge) knowledge, through different knowledge creating methods to acquisition formal or informal experiences into information system to storage. To share and transfer organizational knowledge based on internal network, and finally organizational knowledge thus be applied by organizational learning in organization internal process.

In fact, organization internal process seems to focus on internal supply chain without any relationship with external supply chain; actually, internal processes start from R&D, purchasing, production management, quality and checking, finally examine, then delivering and distribution products for customers to sales services , which will double check the products whether damaged or not during the logistics processes. Therefore, we can found internal processes were interconnected with external processes of supply chain.

However, KM process in organization from internal to external supply chain, in particular, was very complex and with much dynamic information difficult to control. It is also rarely to found researches discussing on relationships between external and internal supply chain management for knowledge management processes.

Therefore, we integrate previous concepts of (1) institutional perspective and organizational learning, and (2) knowledge management in SCM to create a framework of SC-KM learning organization that can assist enterprise in integrating external and internal supply chain with institutional perspective.

AN IMPLEMENTING FRAMEWORK FOR SC-KM LEARNING ORGANIZATION

We propose an implementing framework for SC-KM learning organization, shown in Figure 3. The implementing framework contains four practice-research levels including analysis and descriptions of external and internal supply chain, knowledge management processes (creation, storage, sharing and transferring, applications), and performance measurement for evaluating the organizational SC-KM learning performances. The detail descriptions were mentioned below:

- Level one: analysis and descriptions of external supply chain

  Today, the business faced the challenge "speed to the market with high quality products." Thus, the enterprise needs to understand the pressures from customers and global competitive market, even though the pressures were not from customers. Those pressures also may be from side of suppliers, for instance, how enterprises purchase materials or parts applying Just-in-time system for the requirements of market with ability of quick response. Accordingly, the first step on this level was to find and draw the scope and problems for external supply chain of enterprise.

- Level two: analysis and descriptions of internal supply chain

  The second level was focused on organization internal learning culture understanding, because the internal organization also complex contenting different conditions of management. Each department needs to transfer into different objectives according to the organizational goal; each department thus can be deployed tasks to each employee of department. Therefore, some important steps are considered this point of view from Figure 1 as following:

  1. To define the strategic of supply chain management in a business
  2. To understand the experiences of organizational learning

3. To collect organization learning problems with institutional perspective
4. To find the organization learning for awareness of KM

- Level three: knowledge management processes

  Knowledge management system was considered implementing into organization in this level for sharing and application of organizational knowledge. The major steps were described as follow:

1. Knowledge creation:

   This step was very important and difficult to conduct in whole KM processes because that the extractable knowledge was most from individual experiences in work processes. If organizational members did not have common awareness with learning culture, empowerment, and mechanism, employees would not provide real and true knowledge document; thus, the documents always be information or data instead of useful knowledge. By the way, the past years have seen a dramatic increase in the availability of information technologies, thus, knowledge creation sometimes with the electronic format (new one), sometimes not (old one). Therefore, this step still comprises some critical activities of practices, including:

   ◆ Goals of meeting with Executives

   The participation of executives assists in the organizational learning with more successful opportunities, and gives the project manager and team more confidences. The members of executives are senior managers such as chairperson of each department, CEO, and president.

   ◆ Coordinating the team of KM implementation

   At the conference of executives for KM implementation, the CEO has to assign some key persons to form a team of KM implementation, and this team of KM also has to follow the goal of implementing KM in order to fire up the task of KM implementation.

   ◆ Training and learning concepts of KM for whole organizational employees

   It is an undeniable fact that the opening of KM training & learning is very important for whole the organizational employees. Thus, the team of KM has to consider the possible situation that organization may be without any basic concept or awareness of KM and the individual experiences or documents may be difficult to create and capture. In other words, training for basic concepts of KM also can assist each employee in understanding and discriminating knowledge from data; otherwise, too much data in KM system will let database become garbage.

◆ Building of enterprise knowledge tree

Enterprise knowledge tree represents the kinds of knowledge in an organization. As well as easily understanding how many classifications of knowledge, building organizational requirements to construct organisational knowledge also can facilitate KM system implemented quickly. The enterprise knowledge tree can map the organizational framework such as shown figure 4, which is one particularly simple example.

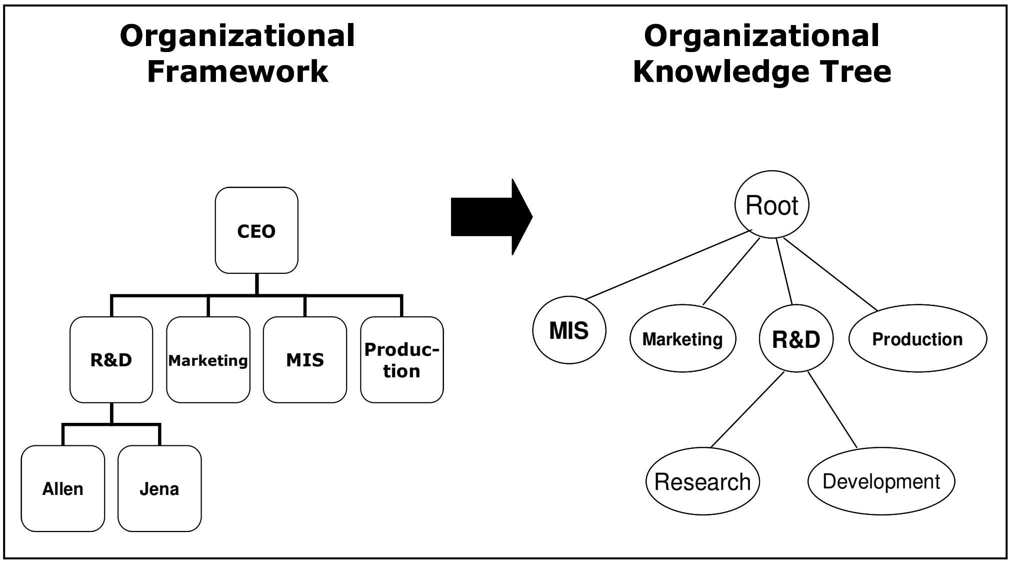

Fig.4. The enterprise knowledge tree

◆ Selecting a suitable sample unit

After building the knowledge tree, selecting a suitable unit became an important task. If the sample department cannot successfully implement KM following the methodology of consultants, other departments cannot successfully implement it, either. Some criteria for selecting a suitable sample department are as follow; members in this unit must possess:

--better comprehension of KM concepts,
--better abilities in using information technology,
--stronger motivation on KM implementation,

--better experiences in constructing knowledge database,
--more complete verifying processes for documents,
--more documents with characteristics of knowledge sharing and using,

Selecting a suitable sample department and seeds was shown in Figure 5.

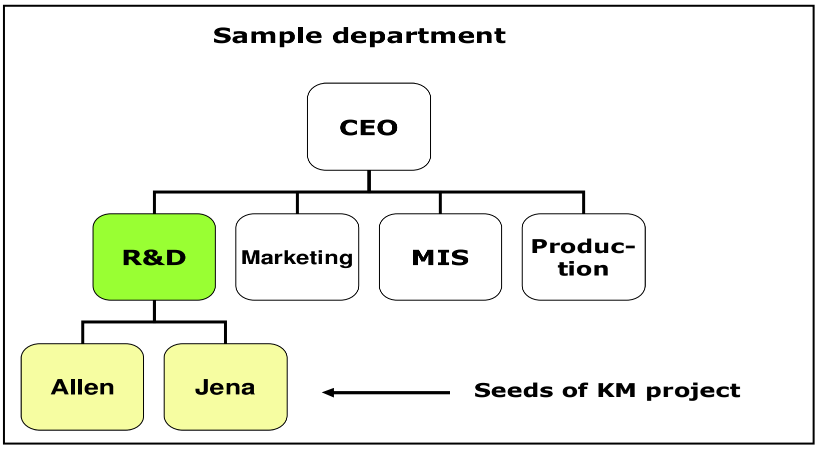

Fig.5. A suitable sample department and seeds of KM project

2. Knowledge storage:
   In practical method, training of knowledge management has to take place for employees before the Knowledge storage. Then they could follow the guideline of KM implementation step by step to capture their experiences or knowledge data in individual personal computers. Storage processes of explicit and implicit knowledge was shown in Figure 6.

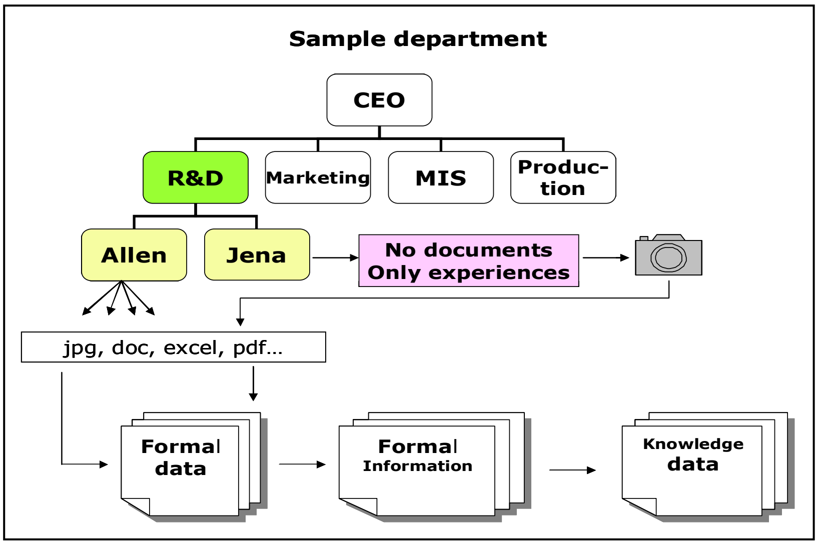

Fig.6. Storage processes of explicit and implicit knowledge

According to the practical consulting experiences, the explicit and implicit knowledge were both difficultly to capture and to storage. For example, in Figure 6, Jena was a technique worker with manual technologies. In her job area, there are few existed records or papers created; thus, for capturing implicit knowledge, the KM team has to use camera or interview to record her work processes and to discuss with her to revise the standard operation processes. After those steps, they can then carry on storage the pictures or video with electronic files and described documents, thus, the implicit knowledge could be performed by visualizing tools. On the side, the explicit knowledge mostly has been transferred into electronic format and storage in personal computer so that storage is not a critical issue; nevertheless, how to distinguish useful data from knowledge was the major problem for KM system implementation.

3. Knowledge sharing and transferring

The most significant purpose for the KM implementation was knowledge sharing and transferring. Organizational knowledge usually hide behind in enterprise different corners, sometimes the operational errors were repeated to appear in different time and different places and different workers; that is, they all do the same work with same operational errors. Repeated errors for an enterprise represented cost and bad managed quality, and those finally will lead to products with terrible problems of quality management. Thus, organizational learning through KM system, a platform to knowledge sharing and transferring, can decrease and prevent the errors repeated appearance. Figure 7 shows the processes of Knowledge sharing and transferring.

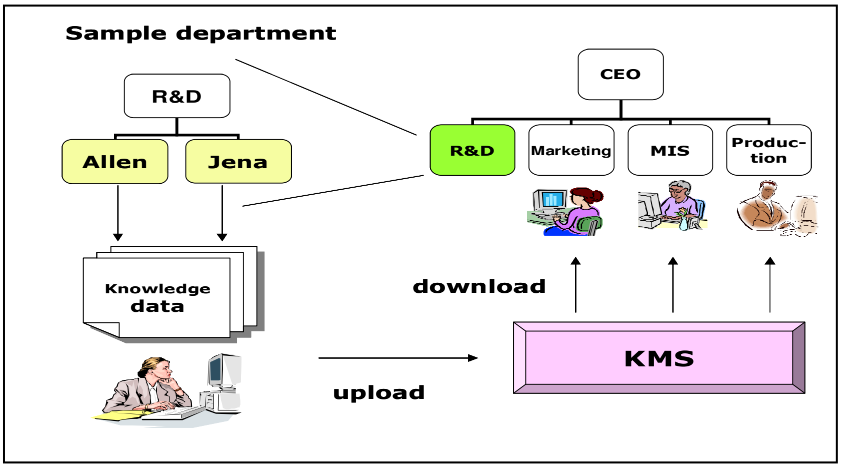

Fig.7. Processes of knowledge sharing and transferring

4. Knowledge applications

The worth of knowledge was to use repeatedly. The processes of knowledge applications was shown in figure 8. When demonstrative department performed knowledge-data edited (design chart) and upload the knowledge-data (design chart) files to KM system, other organizational departments can start to download required files to application after the files are completed accepted by system.

For example, in department of production, Mary was downloading the knowledge-data (design chart) from department of R&D to purchase. She requires the specification of knowledge-data (design chart) to negotiate with different suppliers for outsourcing. In addition to this, Peter also uses the same knowledge-data (design chart) from department of R&D for assembly, because he requires the knowledge-data (design chart) to understand bills of materials (BOM), and then uses them for assembly of products. Finally, different departments use same documents with knowledge for solving different problems; therefore, the organizational learning, one purpose of KM, can be approached through implementation of KM system.

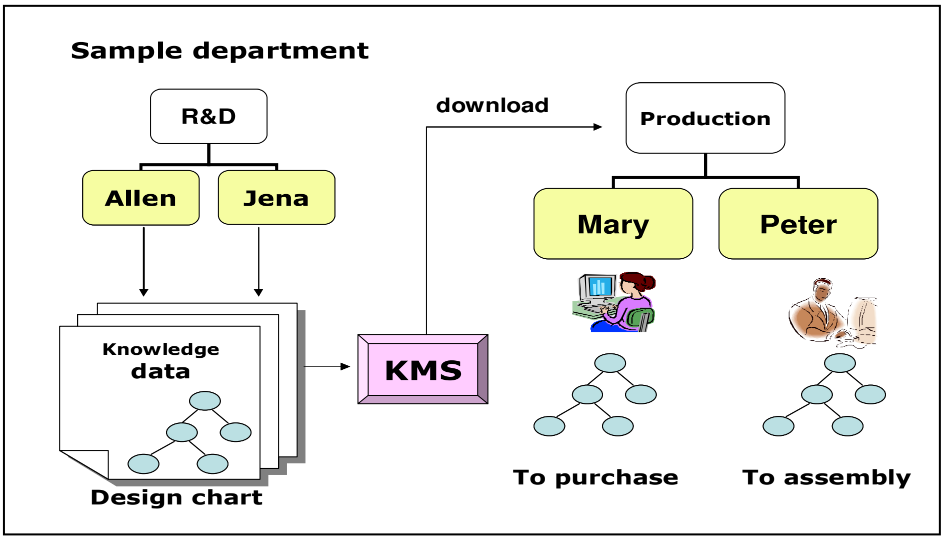

Fig. 8. Processes of knowledge applications

- Level four: evaluation of the organizational SC-KM learning performance

Further and even more importantly, though, this level was end of the framework, the framework needs an evaluated mechanism to view the whole processes of implementation and to confirm whether it is convenience or encountered others problems. We thus refer to the balance scorecard (BSC) as an evaluated mechanism to check the performances of KM implementation.

The balance scorecard (BSC) has four perspectives in the measurement system, that were including the perspectives of learning and growth, business process, customer, and financial. In the center of balance scorecard was the setting of organizational vision and strategy. The related relationships were described as below:

1. Learning and growth perspective
   In the learning and growth perspective was to view whether organization has any learning and growth in organization. On the other hand, this perspective was emphasized learning more than the training.

2. Business process perspective
   This perspective was emphasized the internal business processes and whether response customers' requirements on satisfying products or services quickly. By the way, two kinds of business process were identified such as a) mission-oriented processes, and b) support processes.

3. Customer perspective
   Customer satisfaction and customer services quality were focused on this perspective. Recently, some enterprises start to think about the addition to customer knowledge in order to improve customer services quality for approaching customer satisfaction; thus, can approach the goals of customer satisfaction.

4. Financial perspective
   The basic performances measure was related to the financial of Enterprise. The cash flow and balance sheet were represented the situations of business administration, even according to the financial data could find whether the business appears to managed problems.

We considered conditions of business administration and proposed an implementing framework, from organizational external to internal; then we find organization learning motivation, culture, resources, and activities through implementation of KM system.

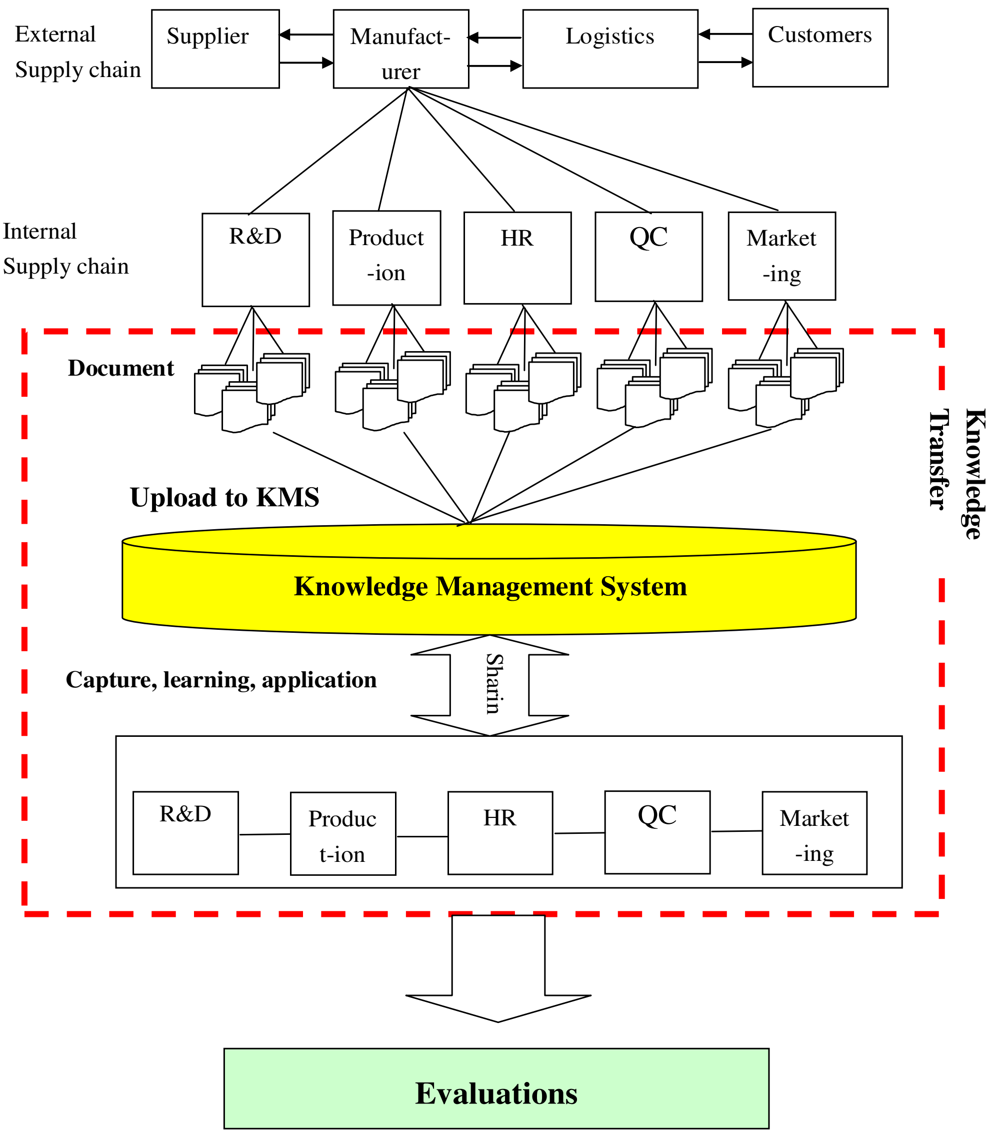

Fig. 3. A framework for SC-KM learning organization

CONCLUSIONS

In this paper, we use academic view according to our lecturers reviewed on supporting KM in SCM with institutional perspective. Then, we also use practical view that we have consulting experiences to construct the organization SC-KM learning framework. We believe that the framework we proposed is useful to assist enterprises on implementing their KM system with institutional perspective, considering conditions both of internal or external supply chain at the same time. By way of conclusion, some critical conclusions were reaffirmed as follow:

1. Supply chain as a learning organization is an important concept.
2. Institutional perspective has become a competitive strategy.

3. Institutional perspective also is one condition in organizational learning environment.
4. How to use institutional perspective to view organizational learning and KM processes in internal supply-chain organization also became a very important issue today; however, rarely investigations were found.
5. Therefore, we propose a framework of SC-KM learning organization that can assist business in integrating external and internal supply chain with institutional perspective. This framework consists of four practice-research levels including analysis and descriptions of external and internal supply chain, knowledge management processes (creation, storage, sharing and transferring, applications), and performance measurement.

ACKNOWLEDGEMENT

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THE IMPACT OF SUPPLY CHAIN COMPETENCIES ON MANAGERIAL PERFORMANCE

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ABSTRACT

This study empirically derive three dimensions of SCM competencies (SCM organizational ability, responsiveness and IT utilization ability) from the data of SCM Logistics Scorecard (LSC) which is one of the general purposed scorecards and consists from actual companies' self- assessment. Differ from the previous researches, the impacts of these SCM competencies on managerial performance are tested by utilizing actual financial bottom line indexes of corresponding companies. The results indicate that higher scores of LSC, which leads to higher level of SCM competencies, can bring significantly positive financial outcomes. Also, stratified analysis depend on several business conditions was conducted. From these several conditions, two dimensions for supply chain circumstances (complexity and uncertainty) were extracted. Results from this stratified analysis indicate that complexity and uncertainty could be considered as requirements for SCM and correspondence to the uncertainty could be a trigger to achieve higher SCM competencies and lead to enhanced managerial performance.

INTRODUCTION

Recently, interest in logistics and supply chain management (SCM) has grown explosively through exposure to fierce competition and changing circumstances. This interest has led many companies to build their supply chain (e.g. Simchi-Levi et al.). However, putting large companies aside, only a few companies can realize to build efficient SCM. This is not due to insufficiency of information technology (IT), but mainly caused by the organizational constraints such as resistance against changing their own business customs and making their own information open. Especially in Japan, such kind of organizational constraints are huge. To breakthrough these constraints, it is necessary for the focal company and members to realize their supply chain performance. Thus, the companies could set up their opportunity for improvement and advance appropriate mechanism to accomplish them.

So as to fulfill the measurement approach, the effective assessment tool which assures to lead financial outcome is extensively required (Dreyer, Shah et al.). Actually, various kinds of scorecards have been developed such as ECR scorecards, QR scorecard, etc, in order to promote SCM associated with IT exploitation. A scorecard is a simplified benchmark methodology to diagnose and evaluate various advantages and disadvantages of their business operations from the point of total optimization of SCM. However, these scorecards are specific for particular industry and consist from detailed and complex evaluation items. Moreover, the relationship between SCM operational performance and financial indexes still has not been made clear through the practical usage of these scorecards.

In this study, we first intend to identify the factors which determine the operational performance of SCM as SCM competencies by using the database of versatile, general-purposed scorecard named SCM logistics scorecard (LSC), which consist from actual companies' self- assessment data. Then, the impact of SCM competencies to the actual financial bottom lines are also analyzed after deriving three hypotheses on their associations as well as providing some implications base on the results.

SCM LOGISTICS SCORECARD (LSC)

Among the diversity of supply chain performance measurement tool, we developed the SCM logistics scorecard (LSC) in corporation with Japan Institute of Logistics Systems (JILS) after conducting survey research on various kinds of SCM scorecards. After several trials, LSC is now utilized as versatile SCM scorecard with a common SCM terminology for the self-assessment and the mutual assessment perspectives (Hamasaki et al., Arashida et al.).
Through this general-purposed scorecard, individual company was able to compare themselves with competitors not only in the same industry cluster but also across the industries. LSC has been now utilized extensively in Japan, China, Finland (Suzuki et.al.).

Appendix 1 represents the assessment based on 20 items which related to 4 fundamental areas for the evaluation purpose in the function of: (1) Corporate strategy& inter-organization alignment (2) Planning and execution capability, (3) Logistics performance and, (4) IT methods and implementation. Each item was designated into five levels, from 1 to 5. The detailed description of each indicator level was also given on the LSC, with the 5th level indicating as the best practice. The score of one integer and a half (for example, 2.5) were also acceptable for manager who placed their companies between two levels. Through this self-evaluation tool, the companies were able to recognize the strengths and weaknesses of their existing working methods from an SCM viewpoint. The ability of company was then compared with competitors and business partners.
Putting high priority on reliability, most data of LSC were collected in the presence of the authors from 2001 in cooperation with JILS. The feedback report was conveyed back to the respondent so as to be an incentive after the data was given by the company. This provided incentive could maintain the reliability level of the achieved data. The feedback report contains the result of the company comparing with others in the same group of industry including the ranking among the competitors.

From 2005, the LSC has been promoted via the business logistics magazines in Japan in order to encourage entrepreneurs to perform the self evaluation and start comparing their competence with the possible rivals. The data has been transferred to the authors by email, which was posted in those logistics magazines. The company evaluation was executed by several email exchanges in order to deliver the identical understanding to the respondent, for example, the instructions of using LSC. From these processes, it was believed that the most reliable data were achieved from the targeted respondents.

The total number of samples was 205 for manufacturing companies, and became 328 when included physical distribution businesses. The attribute of LSC database is shown in Table 1. The average total score, standard deviation, maximum value, and minimum value are also summarized. Cronbach's coefficient alpha 0.917 for these 20 items also indicates high reliability of LSC.

Table 1. LSC data attributes

Industry	Number of data
Foods	38
Chemistry	27
Fiber/Paper Pulp	19
Pharmaceuticals	27
Erectric Machinery	55
Automobile	26
etc	13
Manufacturing Industry	205
Physical Distribution	123
Total	328

	Manufacturing Industry	incld. Physical Distribution
Ave. Total Score	58.67	58.09
Std. Dev.	10.74	10.88
Max	87.5	87.5
Min	29	29

By using these 328 LSC data samples, we attempted to identify the factors which determine the SCM operational performance from the survey in the following section.

IDENTIFYING THE SCM OPERATIONAL PERFORMANCE MEASUREMENT

Concerning on the LSC, which consists of 4 areas, namely, (1) Corporate strategy& inter-organization alignment (2) Planning and execution capability, (3) Logistics performance and, (4) IT methods and implementation, the larger the score, the better performance is considered for all items. It was observed from the survey result that each assessment items had relationships between each other. Accordingly, the specific factors representing operational performance could be categorized by those item relationships. To validate this hypothesis as well as identify the main factors which determine the operational performance of SCM, factor analysis was conducted among the 328 samples (255 companies) from Japanese manufacturing and physical distribution sectors. These 328 samples include the data answered from same company but different division. So we also verified the case that considered 255 samples by calculating average scores on each item to represent the data in general for those companies, but there is no dissimilarity in the structure of factors.

As an initial solution by the principal axis factoring, three factors were extracted (whose eigen value is more than 1) and cumulative contribution rate was 42% by these factors. To simplify factor analysis, the promax rotation was employed. This is because we assume that there are correlations among these factors to some extent. The pattern matrix is shown in Table 2. The larger factor loading (more than 0.4) indicated the strong relationship between each item and factor as shaded in Table 2.

The result indicated that factor 1 had strong relationship with all items of area (1) Corporate strategy& inter-organization alignment and items 2-(1), 2-(2). Since these items may account for the organizational issues in order to build supply chain, it was named 'SCM Organizational Ability.' The consistent observation signified the items, which had large factor loading to the factor 2, were related to agility and adaptability to the market change. Then, the given name was 'Responsiveness.' And as factor 3 had strong relationship with all items of area (4) IT methods and implementation, it was, therefore, named 'IT Utilization Ability.' Since the raw score of each item on LSC can be considered as a result of the capability of these factors, these three factors were identified as the measurement for SCM competencies.

Table 2. Pattern matrix (after promax rotation)

	1	2	3
	SCM Organizational Ability	**Responsiveness**	**IT Utilization Ability**
1-(1) Corporate strategy regarding logistics and its importance	**0.728**	-0.118	0.012
1-(2) Definition of supplier contract terms & degree of information sharing	**0.505**	-0.020	0.183
1-(3) Definition of customer contract terms & degree of information sharing	**0.650**	-0.081	0.062
1-(4) System for measurement and improvement of customer satisfaction	**0.570**	0.244	-0.161
1-(5) System for employee training and evaluation	**0.645**	-0.002	-0.057
2-(1) Strategies for optimizing logistics system resources based on design for logistics	**0.365**	0.232	0.069
2-(2) Understanding of market trends & accuracy of demand forecasting	**0.570**	0.088	0.007
2-(3) Accuracy and adaptability of SCM planning	**0.374**	**0.316**	-0.040
2-(4) Control and tracking of inventory (product/parts/WIP): accuracy and visibility	0.122	**0.385**	0.189
2-(5) Process standardization and visibility	0.068	**0.450**	0.227
3-(1) Just-In-Time	-0.012	**0.695**	0.082
3-(2) Inventory turnover & cash-to-cash cycle time	0.186	**0.567**	-0.060
3-(3) Customer lead time (from order placement to receipt) and load efficiency	-0.071	**0.802**	-0.099
3-(4) Delivery performance and quality	-0.048	**0.621**	0.052
3-(5) Supply chain inventory visibility & opportunity costs	0.167	**0.317**	0.174
4-(1) Electronic Data Interchange (EDI) coverage	-0.119	0.229	**0.496**
4-(2) Usage of Bar Coding / Automatic Identification and Data Capture (AIDC)	-0.105	0.223	**0.530**
4-(3) Effective usage of computers in operations and decision-making	0.277	-0.008	**0.361**
4-(4) Open standards and unique identification codes	0.010	-0.175	**0.820**
4-(5) Decision-making systems and support to supply chain partners	0.146	0.022	**0.475**

The structure of these three factors, SCM competencies, is stable after around 100 data. It could be considered that this factor stability also assure of validity and adequacy of considering these factors as SCM competencies. The features of each factor using the analogy of team sport are explained in Table 3.

Table 3. Definition of three factors indicating SCM operational performance

SCM Organizational Ability	This factor integrates the capability to organize strategy in order to optimize the ability of each player in the team for game supporting. In this case, if you can realize the situation precisely which may change time by time, and be able to deliver a proper tactics to respond and overcome such changeable situation, you need no fear to confront hundred battles.
Responsiveness	Ability to execute individual player (operation unit), especially corresponding to the agility and its quality. In order to be more efficient, it is necessary to know not only the movements of the enemy, but also to expand the range of visualization to avoid own wasteful movements as well as leveling up the ability to derive the situational cooperation play just-in-time.
IT Utilization Ability	The ability in using the weapons as tools to simplify and efficiently implement 2 factors above. In order to strengthen this, it is necessary but not sufficient to introduce various weapons. Besides, for perceiving information and transmitting it to others rapidly, we need both the simplification of the corresponding procedures as well as the standardization and the commonality of the code which can be shared among the players.

IMPACT ON FINANCIAL OUTCOMES

Correlation between SCM competencies and financial indexes

The relationship between supply chain competencies and managerial performance has been somewhat elusive. Several researches have examined the relationship between them. In particular, Closs et al., Stank et al., and Li et al. have established covariance structure models to validate the relationship between SCM competencies and managerial performance. However, they collected the data through the self evaluation items even for managerial performance.

In this section, we use actual financial indexes such as ROA and cash flow as managerial performance and analyze the relationship between three factors extracted from LSC and the these financial bottom line indexes in order to verify that these factors represent as drivers in leading SCM competencies to the financial outcome.

For the relationship between SCM competencies and financial outcome, importance of organizational constraints can be considered very high in order to build an efficient supply chain (eg. Ertek et al.). Therefore, the hypothesis was derived as follows.

Hypothesis 1: There are positive correlations between three factors which represent SCM competencies and financial outcome. And ‘SCM organizational ability’ has much strong correlations.

The analysis utilized the factor score of each company and the corresponding companies’ financial bottom line indexes such as ROA and cash flow from Nikkei Economic Electronic Databank System CD-ROM (NEEDS). For the cash flow, we use two indexes such as cash flow per share and cash flow to sales amount in order to eliminate the diversity among the company scale.

Since it can be considered that there are some amounts of time-lag to reflect SCM operational performance to the managerial performance, and better cash flow can lead better ROA, we use the cash flow as one year later than the LSC data acquisition and two years later for ROA.

Table 4. Correlation between SCM competencies and financial indexes

Manufacturing Industry Sector

	ROA	CF per share	CF to sales amount
SCM Organizational Ability	0.316**	0.331**	0.279**
Responsiveness	0.313**	0.294**	0.203*
IT Utilization Ability	0.250**	0.256**	0.133
N	105	105	105

Physical Distribution Sector

	ROA	CF per share
SCM Organizational Ability	0.350**	0.139
Responsiveness	0.154	0.116
IT Utilization Ability	0.263**	0.136
N	44	44

*: 5% significant、**: 1% significant N: number of samples

Table 4 presents the results of correlation analysis, which support the hypothesis one. As we can see, all three factors, which determine one's own SCM competence, had a significant positive correlation with the financial indexes. The results indicated that the improvement of three factors had positive impact on the financial outcomes such as ROA and cash flow. Especially, 'SCM Organizational Ability' factor, which account for the organizational issues, has the highest correlations to financial indexes comparing to other competence factors.
Since we used the data for cash flow one year later than those of LSC and two years later for ROA, the time series data also indicated that improving SCM competencies brought positive impact to cash flow initially, then led to the ROA improvement. The relationship between 'SCM Organizational Ability' and ROA in manufacturing sector is exhibited in Figure 1.

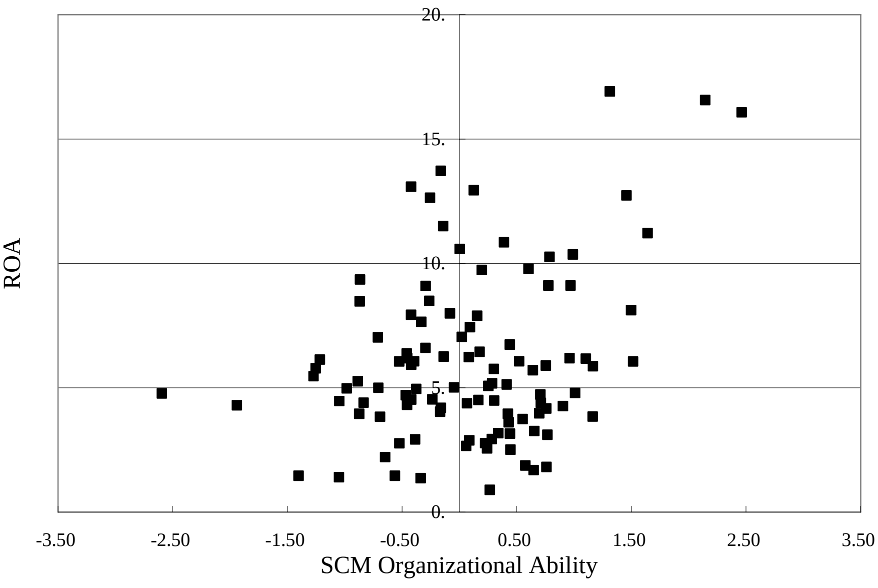

Figure 1. Distribution of SCM Organizational Ability and ROA

Stratification by SCM competencies level

The outline of each level of LSC can be summarized as follows.

Level 1: No control or management for SCM.

Level 2: <Local Optimized Distribution level> There is no linkage between each distribution activity and customer demand. Each operation unit seeks their own self optimization.
Level 3: Each distribution activity starts having linkage to its customer demand and to the market. However, this level still unable to establish a complete synchronization in the supply chain.
Level 4: <In-bound SCM level> All activities within the company are integrated together to generate the efficient distribution system with the ability to link with customer demand and market trend.
Level 5: <Best practice> One focal company can build “Out-Bound SCM” involving several organizations to forms their own supply chain. The focal company could play a role as a leader for managing the supply chain.

It can be considered that in order to reflect operational effort regarding to SCM to the financial outcomes, each operation should have linkage to customer demand and to the market which are the driver for supply chain. Hence, another hypothesis was derived regarding to the relationship between SCM competencies level and financial outcomes.

Hypothesis 2: Improving SCM competencies to achieve more than the average level brings much higher positive impact on financial indexes.

In order to verify this hypothesis, we classified ‘SCM Organizational Ability’, which has most significant correlations between financial indexes, into two groups dividing at its score zero, the overall average for more detail analysis. Score zero corresponding to 3.09 of the LSC raw score which means that each activity has a linkage to the customer demand and to the market as a whole. Because of the limitation of number of samples, we focus on manufacturing industry sector in this section.

Table 5 shows the correlation between ‘SCM Organizational Ability’ and financial indexes with classification, which support the hypothesis two. The fact could be pointed out from the results that when the score of ‘SCM Organizational Ability’ was less than zero, the overall average, only a weak relationship with financial indexes was noticed. On the other hand, when the score exceeds zero, a higher positive correlation was observed (Table 5 and Figure 2). From these observations, it could be summarized that improving ‘SCM Organizational Ability’ to achieve more than the overall average brought significantly positive on financial indexes. To make it visible, linear regression lines for two groups are also shown in Figure 2.

Table 5. Correlation between SCM Organizational Ability and financial indexes

Manufacturing Industry Sector

	ROA	CF per share	CF to sales amount
High SCM Organizational Ability	0.557**	0.577**	0.279**
N	56	56	0.203*
Low SCM Organizational Ability	0.287	0.139	0.133
N	49	49	105

*: 5% significant、**: 1% significant N: number of samples

Likewise, the same observable fact was noticed from other two factors, 'Responsiveness' and 'IT Utilization Ability.' Consequently, we obtained a focal implication to companies to encourage SCM improvement through LSC. In the case when diagnosed score of some factors were less than zero, the LSC items which had a large impact on that factor will be scrutinized and improved urgently to raise the score of that factor. This was the fundamental attempt for reflecting the shop floor effort to the managerial performance. The impact level of each item on each factor was studied and shown as factor loadings in Table 2.

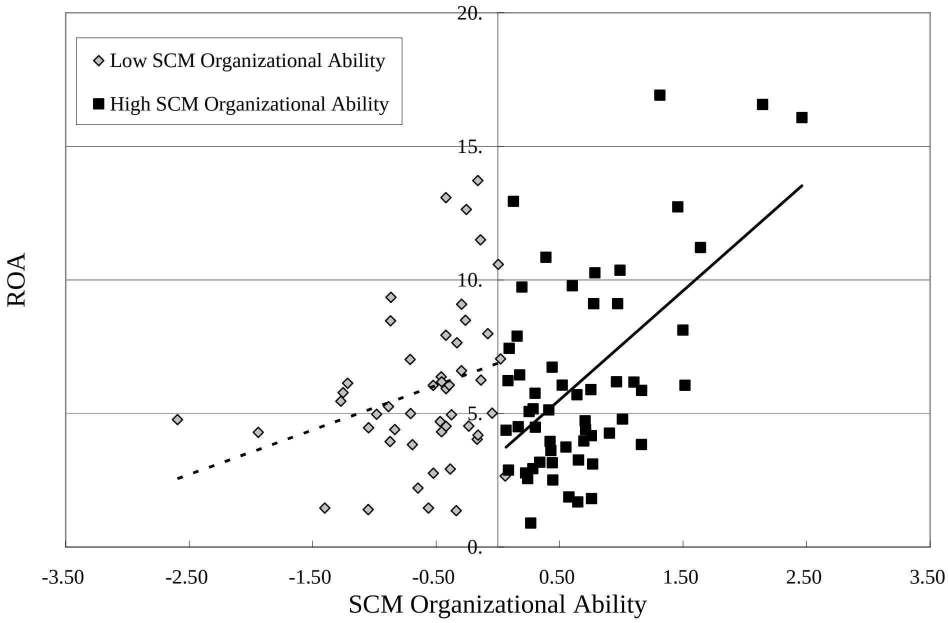

Figure 2. Distribution of SCM Organizational Ability and ROA with classification

Stratification by Business Conditions

In the previous sections, relationship between SCM competencies and financial outcomes for all the samples are discussed. Subsequently, differences among the industry types due to their business conditions are considered.

During the LSC data collection the information about companies' business conditions was not gathered, and therefore the stratification in this section had to be done with secondary data. In this study, 13 business condition related items are utilized. And as for industry types, the same classification as in the LSC was used. These industry types, business condition items and scoring presented in Table 6. Scoring for each industry mainly depend on Fujimoto (2000), governmental reports and annual financial reports.

In order to derive main factors which represent industries' SCM circumstances, principal component analysis with varimax rotation was conducted for these 13 items. As a result, four factors were initially extracted with their eigen value more than one. In this section we utilize first two factors which has larger eigen value than others with a cumulative contribution rate of 66.6 %.

Table 6 Scoring of industry type for 13 business conditions

	Foods - Daily delivery	Foods - Materials and processed foods	Chemical - Materials	Chemical - Consumer goods	Fiber	Paper/Pulp
Seasonal changes in demand	5	2	1	2	1	1
Known trends in demand	4	5	4	3	5	5
Influence of economic trends on operations	2	2	3	3	4	1
Influence of weather	5	4	1	3	5	1
Level of competition in the market	3	5	1	2	5	1
Difficulty of understanding customer needs	4	4	3	4	4	2
Difficulty of demand forecasting	4	3	3	3	3	2
Importance of design	3	3	1	5	5	2
Importance of product appearance	4	3	1	4	5	2
Number of component types in products	2	2	2	1	2	1
Number of production processes	1	2	2	2	3	2
Number of requested functions	2	2	2	3	1	2
Level of internationality	2	2	3	3	2	1

	Pharmaceutical	Electric Machinery - Consumer products	Electric Machinery - Business products	Automobile - Assembly	Automobile - parts
Seasonal changes in demand	2	5	4	2	2
Known trends in demand	2	3	2	5	5
Influence of economic trends on operations	3	4	5	5	4
Influence of weather	1	1	1	1	1
Level of competition in the market	3	3	2	3	3
Difficulty of understanding customer needs	2	3	3	3	1
Difficulty of demand forecasting	2	4	2	4	1
Importance of design	1	5	3	5	2
Importance of product appearance	1	5	1	5	1
Number of component types in products	1	4	3	5	2
Number of production processes	2	4	3	5	2
Number of requested functions	2	3	3	5	2
Level of internationality	3	4	3	5	2

Table 7 Pattern matrix (after varimax rotation)

	1	2
	Production Complexity	**Demand Uncertainty**
Seasonal changes in demand	0.162	0.313
Known trends in demand	-0.047	0.189
Influence of economic trends on operations	**0.819**	-0.189
Influence of weather	-0.476	**0.669**
Level of competition in the market	0.037	0.301
Difficulty of understanding customer needs	-0.117	**0.862**
Difficulty of demand forecasting	0.297	**0.894**
Importance of design	0.509	**0.667**
Importance of product appearance	0.349	**0.847**
Number of component types in products	**0.894**	0.233
Number of production processes	**0.948**	0.116
Number of requested functions	**0.816**	0.169
Level of internationality	**0.868**	0.165

Pattern matrix is shown as Table 7. The larger factor loading (more than 0.6) indicated the strong relationship between each item and factor as shaded in Table 3. The result indicated that factor 1 had strong relationship with items which concerning to production features. On the other hand, items which had large factor loading to factor 2 were related to the difficulty of accurate demand grasping. So, factor 1 and factor 2 were respectively named as production complexity and demand uncertainty. These factors could be considered as requirements for building efficient supply chain.

Figure 3 shows the distribution of principal component scores of each industry type for product complexity and demand uncertainty. As we can see, it can be divided into four groups depend on these two factors.

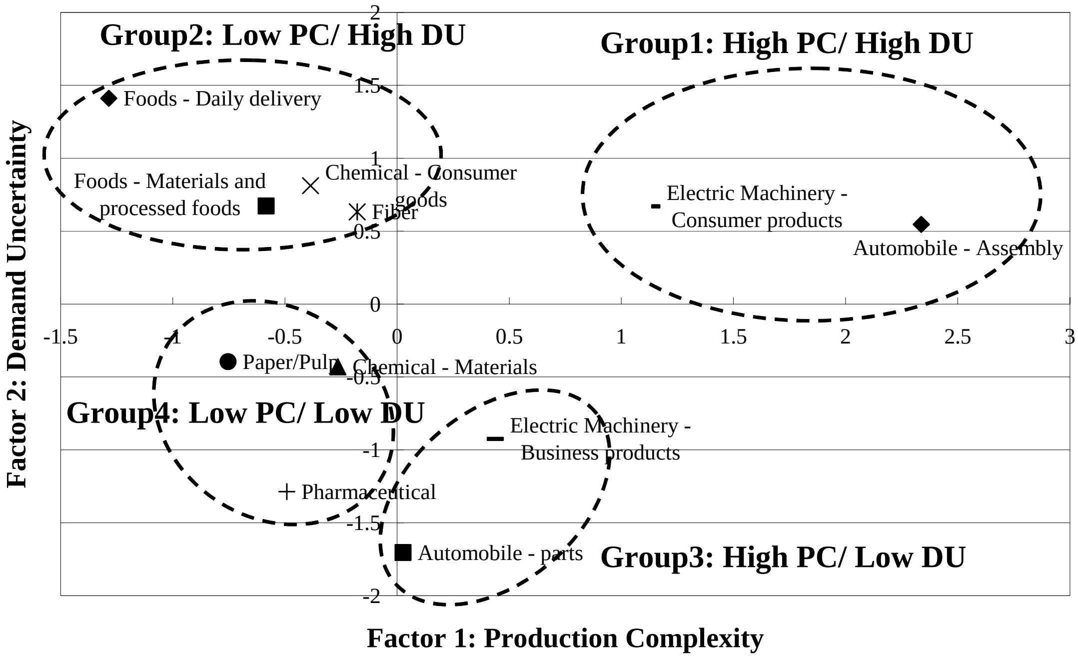

Figure 3 Distributions of industry in manufacturing sector

It can be considered that these business conditions may affect to supply chain formation and its operational performance. Hence, another hypothesis was derived.

Hypothesis 3: Business conditions influence on the SCM competencies and those relationships between financial performances

Table 6 shows the results of ANOVA for SCM competencies factor scores. The results indicated that SCM organizational ability and IT utilization ability were noticed to have differences among uncertainty with 5% significance but none of the SCM competencies has significant difference among complexity.

In addition, better performance of SCM could result in generating higher correlation between SCM operational performance and financial indexes as shown in Table 5. In this table, another financial index, inventory turnover period is added. Although this index did not show significant correlation in the case of all samples, it could be considered that these are because of the confounding effect caused by the diversity among different industrial attributes.
After deriving this stratification, another features concerning to the relationship between SCM competencies and financial outcomes are observed. In high demand uncertainty groups (group 1 and 2), much strong correlation between

SCM competencies and financial indexes are observed not only for cash flow and cash flow but also for inventory turnover period. On the other hand, group 3 has no significant relationship with financial outcomes.

Table 6 Results of ANOVA for SCM competencies factor scores

SCM Organizational Ability

Source	DF	Sum of squares	Mean squares	F	Pr>F
Complexity	1	0.002	0.002	0.002	0.964
Uncertaity	1	3.961	3.961	4.577	0.034*
Complexity * Uncertainty	1	0.046	0.046	0.053	0.819
Error	185	160.089	0.865		

Responsiveness

Source	DF	Sum of squares	Mean squares	F	Pr>F
Complexity	1	0.004	0.004	0.004	0.948
Uncertaity	1	0.821	0.821	0.947	0.332
Complexity * Uncertainty	1	0.088	0.088	0.101	0.751
Error	185	160.333	0.867		

IT Utilization Ability

Source	DF	Sum of squares	Mean squares	F	Pr>F
Complexity	1	0.58	0.58	0.728	0.395
Uncertaity	1	3.499	3.499	4.394	0.037*
Complexity * Uncertainty	1	0.613	0.613	0.770	0.381
Error	185	147.331	0.796		

*: 5% significant

Table 7 Correlation between SCM competencies and financial indexes after stratification by business conditions

Group1: High Complexity/ High Uncertainty

	ROA	CF per sales	Inv. t/o period
SCM Organizational Ability	0.303	0.434*	0.107
Responsiveness	0.29	0.14	-0.448*
IT Utilization Ability	0.247	0.714**	-0.089
N	15	16	16

Group2: Low complexity/ High uncertainty group

	ROA	CF per sales	Inv. t/o period
SCM Organizational Ability	0.262	0.161	-0.315*
Responsiveness	0.232	0.191	-0.340*
IT Utilization Ability	0.134	0.180	-0.150
N	36	36	36

Group3: High complexity/ Low uncertainty group

	ROA	CF per sales	Inv. t/o period
SCM Organizational Ability	0.287	0.165	0.012
Responsiveness	0.142	-0.079	-0.282
IT Utilization Ability	0.230	-0.041	-0.003
N	19	20	20

Group4: Low complexity/ Low uncertainty group

	ROA	CF per sales	Inv. t/o period
SCM Organizational Ability	0.483**	0.511**	0.151
Responsiveness	0.465**	0.488**	0.248
IT Utilization Ability	0.281	0.148	0.132
N	34	34	34

*: 5% significant、**: 1% significant N: number of samples

These results could be assumed to be depending on the features of their customers. Due to the fact that, the final customer always tend to expect company severely to be more sensitive to market change, correspondence to this uncertainty could be a trigger to achieve higher SCM competencies and lead to enhanced managerial performance. The tendency that higher level of SCM competencies can bring much positive correlation with financial outcome is also corresponding to the previous results. These findings would appear to support Hypothesis 3.

CONSIDERATION

To verify these results and difference of each group by LSC data, the multinational scaling analysis (MDS) using PROXSCAL algorithm was applied for LSC 20 items into 4 groups. The utilized scaling model is Weight Euclidean of full proximities matrixes, proximities transformations is interval with two dimensions solution (0.09 normalized raw stress and 95% Tucker's Coefficient of Congruence). Figure 4 shows the plotting of Normalized raw stress as well as the Tucker's Coefficient of Congruence for the different dimensional solutions. The figures show slight elbows at n=2 dimension, supporting two-dimensional solution for both four countries and seven categories analysis.

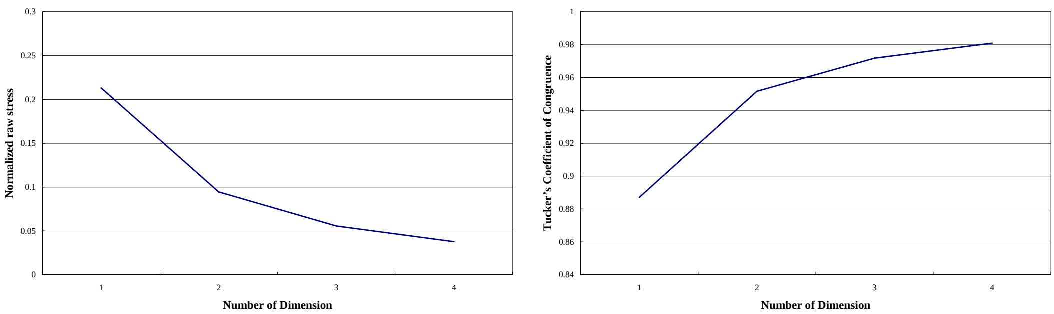

Figure 4 Normalized raw stress and Tucker's coefficient of congruence

As a consequence of PROXSCAL, the final coordination of 20 items from the proximities matrixes of 4 groups is shown in Table 8 and Figure 5. Dimension 1 could be interpreted as performance orientation and dimension 2 as performance driver orientation. Higher the score of dimension 1, company tend to more sensitive for inventory status such as inventory turnover and its visibility. For dimension 2, higher score means more oriented to IT utilization and on the other hand, lower score means attaching much importance to organizational relationship.

The individual space of four groups is plotted in two-dimensional axis which is presented in Figure 6.

Table 8 Coordination of 20 items in LSC

	Dimension	
	1	2
1-(1) Corporate strategy regarding logistics and its importance	-0.38	-1.46
1-(2) Definition of supplier contract terms & degree of information sharing	-1.02	-0.40
1-(3) Definition of customer contract terms & degree of information sharing	-0.86	-0.94
1-(4) System for measurement and improvement of customer satisfaction	0.05	-0.95
1-(5) System for employee training and evaluation	0.96	-0.93
2-(1) Strategies for optimizing logistics system resources based on design for logistics	-0.14	-0.30
2-(2) Understanding of market trends & accuracy of demand forecasting	-0.54	-0.50
2-(3) Accuracy and adaptability of SCM planning	-0.59	0.72
2-(4) Control and tracking of inventory (product/parts/WIP): accuracy and visibility	0.33	-0.05
2-(5) Process standardization and visibility	0.75	0.09
3-(1) Just-In-Time	0.51	0.75
3-(2) Inventory turnover & cash-to-cash cycle time	1.56	0.34
3-(3) Customer lead time (from order placement to receipt) and load efficiency	0.48	-1.56
3-(4) Delivery performance and quality	-1.29	0.18
3-(5) Supply chain inventory visibility & opportunity costs	2.29	0.17
4-(1) Electronic Data Interchange (EDI) coverage	-1.40	1.10
4-(2) Usage of Bar Coding / Automatic Identification and Data Capture (AIDC)	0.02	2.22
4-(3) Effective usage of computers in operations and decision-making	-1.74	-1.15
4-(4) Open standards and unique identification codes	0.01	1.47
4-(5) Decision-making systems and support to supply chain partners	1.00	1.20

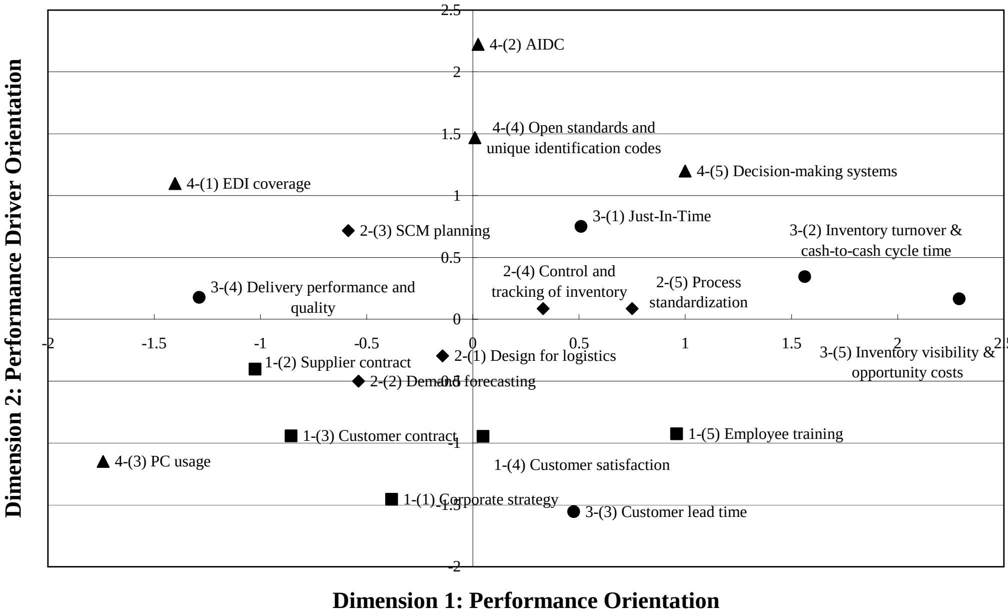

Figure 5 Coordination of 20 items in LSC

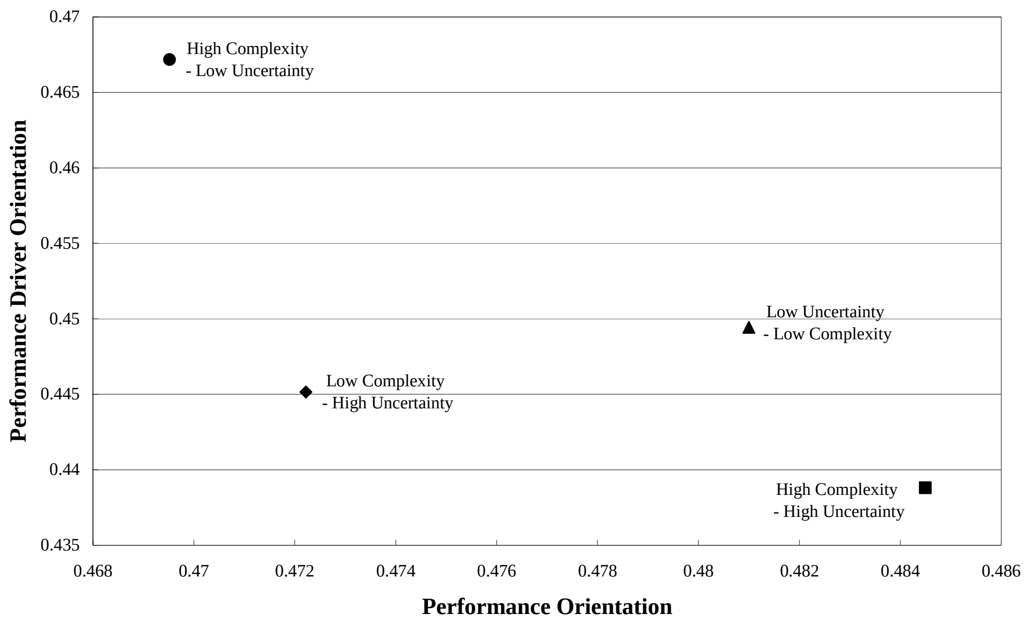

Figure 6 Distribution of four groups

It was clearly observed from the result that the positions of four groups are totally different. Particularly, group 1 could be considered as more performance oriented, putting a high value on organizational relationship. On the other hand, group 4 could be grasped as thinking much of IT utilization. This diversity a detailed analysis, which takes into account the difference of each industry, is an issue for the future research.

CONCLUSIONS AND IMPLICATIONS

In this study, we first identified the factors which determined SCM competencies by using LSC data. Those were 'SCM Organizational Ability', 'Responsiveness', and 'IT Utilization Ability.' Significant positive correlation between these three factors and financial indexes were also proved. By considering time-lag among the LSC data acquisition and financial indexes, we can verify quantitatively that improving SCM competencies brought positive impact to cash flow initially, and then led to ROA improvement.

Based on these results, classification analysis for the SCM competencies level was conducted. The most remarkable fact was pointed out from the results that only a weak relationship with financial indexes was noticed when the score of three factors was not relatively high. However, when the score exceeded to some extent, a higher positive correlation was observed.

Subsequently, stratified analysis depend on several business conditions was conducted. From these several conditions, two dimensions for supply chain circumstances, complexity and uncertainty were extracted. Results indicate that complexity and uncertainty could be considered as requirements for SCM and correspondence to the uncertainty could be a trigger to achieve higher SCM competencies and lead to enhanced managerial performance.

The results and findings from this research would have potential implications for industrial sectors not only in Japan but also in various countries to improve their supply chain performance. LSC could be considered as the simple benchmarking tool to compare companies' performance with their competitors.

The self-diagnosis system of LSC based on these results was also utilized extensively in Japan, China, Finland and Thailand. While the data from China, Finland and Thailand companies were excluded in this paper, research effort will be focused on this sector as well as the classification analysis among the industry type of overseas as the future work. Moreover, the attempt will be made to collect more data from various countries to perform the global comparative study through the LSC. The observation on the country institution such as business customs and infrastructures will also be discussed to see the structural difference of SCM competencies among the countries.

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RELATIONSHIPS BETWEEN TWO APPROACHES FOR PLANNING MANUFACTURING STRATEGY: A STRATEGIC APPROACH AND A PARADIGMATIC APPROACH

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ABSTRACT
Two approaches for planning manufacturing strategy were identified as a strategic approach and a paradigmatic approach. The key decisions of the strategic approach are located in the choices of competitive priorities, and the key decisions of the paradigmatic approach are located in the choices of manufacturing paradigms. Relationships between these two approaches in turbulent environment were empirically studied. Three hypothesis models on the relationships were founded with Structure Equation Modeling (SEM) and tested with 107 samples from Chinese manufacturing industry. The results show that in turbulent environment, business strategy has direct influence on the key decisions of each approach, and it is better to make the key decisions based on business strategy respectively.

INTRODUCTION
Manufacturing strategy has different paradigms, such as competing through manufacturing, strategic choices in manufacturing, best practices. Accordingly, there are different approaches for planning manufacturing strategy. Two approaches were identified in this paper: a strategic approach and a paradigmatic approach. In the strategic approach, key decisions on manufacturing strategy are located in the choices of competitive priorities, which are known as manufacturer's choice of emphasis among key capabilities, such as quality, cost, delivery, flexibility. In the paradigmatic approach, key decisions on manufacturing strategy are located in the choices of manufacturing paradigms which include best practices and manufacturing systems, such as Just in Time (JIT), Agile Manufacturing. A compatible and complementary relationship can be found between these two approaches, and there are close relationships between choices of competitive priorities and the choices of manufacturing paradigms. However, how to plan manufacturing strategy according to these two approaches has not been fully examined. Since manufacturing strategy must support business strategy whichever approach is used, we suggest examine the relationships between two approaches through analyzing the relationships among the key decisions of two approaches and business strategy.

The remainder of this paper is organized as follows. In the second section, literatures on the relationships between two approaches were reviewed, and three hypotheses on the relationships were proposed. The third section described the research methodology. In the fourth section, the results of measuring manufacturing strategy and business strategy were reported. The hypotheses were tested in the fifth section. In the last section, we concluded and discussed the results, and made recommendations for future studies.

LITERATURE REVIEW

Today's competitive environment is a turbulent environment full of changes, i.e. ubiquitous availability and distribution of information, accelerating pace of change in technology, globalization of market, global wage and job skills shifts, environmental responsibility and resource limitations, and increasing customer expectation etc. (Hughes, 1997). Many changes are difficult to be predicted, which means the changes have an uncertainty attribute (Correa, 1994). These changes cause much complexity for manufacturing or logistics systems in the production process, new product development, inbound and outbound logistics, sales process, and production engineering (Perona and Miragliotta, 2004). How to deal with these changes and uncertainty is regarded as the most important capability for firms and also for manufacturing systems to complete in the turbulent environment. Many studies can be found on this topic (Wiendahl and Scholtissek, 1994; Prastacos et al., 2002). In this paper, we focus on the capability in manufacturing, which is also the core requirement on manufacturing strategy in the turbulent environment. This is much different from the production core in the traditional competitive environment, which is to move toward the most efficient, low-cost state by investing in automation and standardization in response to predictably maturing markets (John et al., 2001). Accordingly the approach for planning manufacturing strategy in the turbulent environment also needs to be changed.

Traditionally, a common theme in manufacturing strategy research has been describing manufacturer's choice of emphasis among key capabilities, which can be described with the term 'competitive priorities' (Ward et al, 1995). Ward and Duray (2000) further presented a context model for manufacturing strategy, among which competitive environment, business strategy and manufacturing strategy are sequentially linked and affect one another from top to down. Kim and Arnold (1996) empirically studied the constructs and linkage among the detailed components of manufacturing strategy and proposed a process model for operation as shown in Figure 1. This process model regarded that components of manufacturing strategy included competitive priorities (relative importance of competitive capabilities), manufacturing objectives (relative emphasis on performance targets), and action plans (choice of improvement programs). In this paper, the approach for planning manufacturing strategy based on the choices of competitive priorities is called as "a strategic approach". This approach focuses on the external consistency among manufacturing strategy, business strategy, and other functional strategies, such as marketing strategy; and the internal consistency among the components of manufacturing strategy, such as competitive priorities and action plans. It is theoretically attractive, but difficult to generate new creative ideas. Because of the internal and external consistency, the market strategy and the order-winning criteria decided by a firm will determine the choices of process, and also make firms miss the step changes, such as adopting some new practices (Voss, 1995). In addition, under the turbulent environment, the strategic approach is facing some other problems. For example, firms have to satisfy simultaneous demands of low cost, flexibility, speed and variety requirements, but not special ones selected from them (Brown, 2001; Shi and Daniels, 2003). A paradigmatic approach for planning manufacturing strategy can avoid these shortcomings.

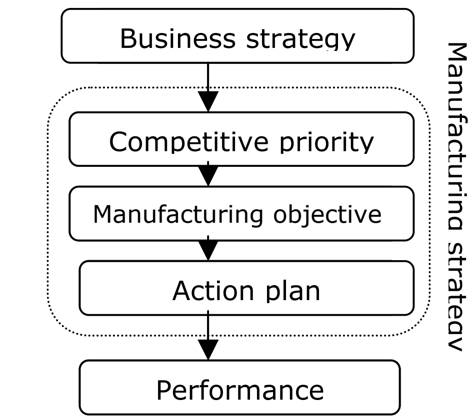


Fig. 1 A model of strategic approach

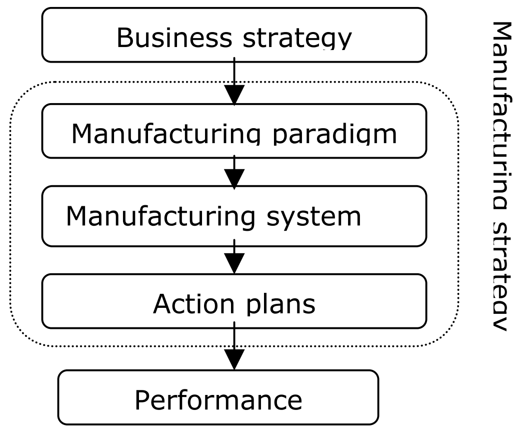


Fig. 2 A model of paradigmatic approach

A paradigmatic approach regards that innovative manufacturing paradigms and practices can embody new rules and sets of coherences between various choices about manufacturing, and provide best practices for benchmarking. In detail, there are three components in this approach as shown in Figure 2. (1) Action plans: detailed plans on practices, techniques or programs, such as just in time deliveries, quality cycles, Kanban, statistical process control, quality function deployment, etc. Bolden et al. (1997) has conclude over 100 manufacturing practices. (2) Manufacturing systems: innovative systems including the systemic and coherent combinations of practices. For example, Just-In-Time manufacturing system includes 10 kinds of techniques or practices (White, 1990). Spina (1998) call these systems as manufacturing models. Clark (1996) named Advanced Manufacturing Systems (AMS) as shorthand for these systems or best practices in production, design and engineering, and logistics. In the turbulent environment, dealing with change becomes a necessary capability of manufacturing systems. Though there is no common perspective on the paradigm for dealing with change, we can find many best practices or manufacturing systems with the capability of dealing with change, for example, Bionic Manufacturing Systems, Honolic Manufacturing Systems, Fractal Companies, etc. (3) Manufacturing paradigms, that is limited sets of new principles that underpin the techniques and pool together various manufacturing systems or models (Spina, 1998). This approach is very attractive in practice, but also facing some criticisms. For example, it is difficult to convergent different manufacturing systems into a unifying paradigm, and it may drive companies to become similar to each other (Spina, 1998).

Because of the functions and shortages of these two approaches, a compatible and complementary relationship between them has been found (Voss, 1995; Hayes and Pisano, 1996; Clark, 1996; Morita and Flynn, 1997; Spina, 1998). Voss (1995) concluded that different paradigms of manufacturing strategy have their strengths and weaknesses and each partially overlaps the other. Clark (1996) argued manufacturing's true competitive power lies in integrating the capability of an advance manufacturing systems (AMS) with strategic management of manufacturing. Morita and Flynn (1997) empirically examined the linkage between different paradigms of manufacturing strategy. Spina (1998) provides evidence that paradigmatic views and strategic choices in manufacturing are compatible and complementary. However, how to plan manufacturing strategy according to these two approaches has not been fully studied. A critical question is on the relationships between competitive priorities and manufacturing paradigms which are the key decisions of two approaches respectively. Different proposals can be found on the relationships, but there is no consensus. For example, make decisions on manufacturing paradigms based on competitive priorities or based on business strategy directly. This question is critical for setting up the planning process model of manufacturing strategy based on these two approaches. Since manufacturing strategy must support business strategy whichever approach is used, we suggest examine the relationships between these two approaches through studying the relationships among business strategy, competitive priorities, and manufacturing paradigms. Three proposals on the relationships can be found from literature review.

Firstly, linking manufacturing paradigms to business strategy via competitive priorities is a possible choice. This proposal is based on the close relationships between manufacturing paradigms and competitive priorities, and the close relationships between competitive priorities and business strategy. Manufacturing paradigms come from manufacturing systems which must reflect a company's manufacturing strategy and the chosen competitive priorities (Safsten and Winroth, 2002). Making decisions on manufacturing systems based on competitive priorities can be found in many studies. For example, linkages between different kinds of manufacturing systems and business performance in term of cost, quality, delivery, and flexibility have been set up in many studies (Miltenburg, J., 1995; Duda and Cochran, 2000) This proposal has also been reflected in the model proposed by Kim and Arnold (1996), which links action plans (including some best practices) to business strategy through competitive priorities. Therefore, one hypothesis is proposed based on the suggestion as follows.

H1: Competitive priorities accounts for a significant portion of the relationships between business strategy and manufacturing paradigms.

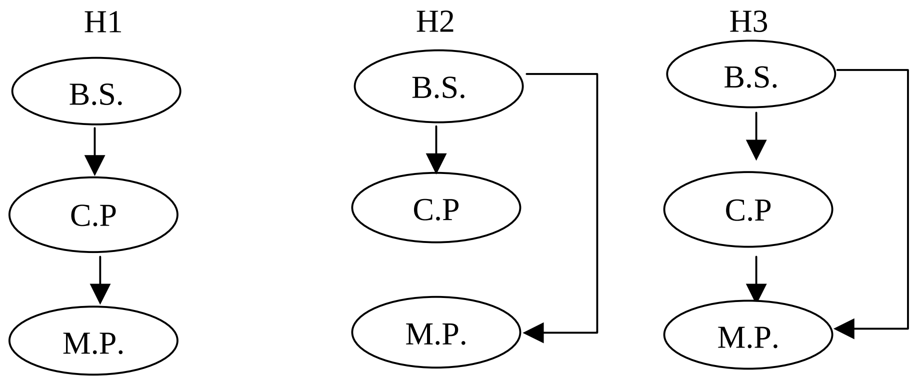
Secondly, direct relationships can be found between manufacturing systems and business strategy and between best practices and business strategy. For example, Kim and Lee (1993) linked different kinds of manufacturing systems to business strategy in terms of cost efficiency and differentiation. Carrie et al., (1994) linked different manufacturing systems to business strategy in terms of defenders, prospectors, analyzers, and rectors. Vichkery and Droge (1993) linked different practices to business strategy. On the other hand, it is necessary to link manufacturing systems and best practices to business strategy. Though best practices have positive relationships with performance, it is wrong to assume that the linkage between best practice and high performance is universal or automatic (Hiltrop, 1996). Hiltrop (1996) and Pilkington (1998) already found without a good integration with business strategy, best practices would not lead to good performance. Pilkington (1998) pointed that the alignment of manufacturing with the rest of the corporate strategy has often been ignored in many firms when pursuing a new action plan. Therefore, another hypothesis is proposed as follows based on the suggestions.

H2: Business strategy influences decisions of manufacturing paradigms directly.

The differences between these H1 and H2 may be caused by the changes in the competitive environment. Under the stable environment, the hierarchical decision making along with business strategy, competitive priority, and action plans does working because we need not adjust business strategy and manufacturing systems frequently. However, under the turbulent environment, facing some many changes, we need to revise our strategy and decisions in manufacturing frequently. Therefore, the relationships between business strategy and manufacturing paradigms become closer and more important. Based on H1 and H2, we may wonder that manufacturing paradigms can be linked to business strategy through these two different approaches as explained in the former two hypotheses. At last, we propose the third hypothesis as follows.

H3: Both business strategy and competitive priorities directly influence decisions on manufacturing paradigms.

According to these three hypotheses, we set up three models as shown in Figure 3. Based on H1, Model A has a serial linkage among business strategy (B.S.), manufacturing paradigms (M.P.), and competitive priorities (C.P.). Based on H2, Model B has current linkages between manufacturing paradigms and business strategy and between competitive priorities and business strategy. Based on H3, Model C has a completed linkage among manufacturing paradigms, competitive priorities, and business strategy.



Model A Model B Model C

Fig. 3 Hypothesis models on the relationships between two approaches.

In summary, there are three hypotheses standing for different relationships between manufacturing paradigms, competitive priorities, and business strategy. The purpose of setting up the linkages is to reflect the requirement of business strategy on the decisions of manufacturing decisions, and to force different departments including manufacturing to follow one common guideline identified by the strategy. When firms fail to recognize the relationships between manufacturing decisions and business strategy, they may become saddled with seriously noncompetitive production systems, which are expensive and time-consuming to change (Skinner, 1969). Furthermore, different linkages may have different influence. For example, a long and indirect linkage may lose or distort the requirements and other information. Therefore, it is necessary to compare different linkages and give out a good suggestion. The purpose of this paper is to examine which linkage is the best based on a survey, and give suggestions for the planning process of manufacturing strategy.

RESEARCH METHODOLOGY

We introduced the research methodologies used in the section. In the first subsection, we review thirty one different kinds of manufacturing systems and identify four important manufacturing paradigms for dealing with change. In the second subsection, original measurement scales for the manufacturing paradigms, competitive priorities, and business strategy in the survey were developed. In the third subsection, we described the methodologies for testing the measurement scales of the manufacturing paradigms and the methodologies for testing the hypotheses. In the last subsection, we described the survey instrument and samples in the survey.

Manufacturing Paradigms

According to the conception of manufacturing paradigms, we can conclude manufacturing paradigms based on the common characteristics of manufacturing systems. In the study, we focus on the turbulent environment, and the capability of dealing with change and uncertainty in manufacturing. On the other hand, manufacturing systems and practices are also sharing some common characteristics in dealing with change. For example, Wiendahl and Scholtissek (1994) concluded that manufacturing systems deal with changes through developing new designs for production structures and dynamic processes. Monostori et al. (1998) concluded that manufacturing systems deal with changes in three ways, i.e. (1) enhancing the reactivity and proactivity of traditionally structured system by sophisticated new control systems, (2) constructing decentralized, distributed systems; (3) developing adaptive systems, which are able to learn from past history.

In this study, manufacturing paradigms in the turbulent environment are concluded from the common characteristics or approaches for dealing with change shared by different manufacturing systems. In detail, we examined the work in the area of manufacturing systems, most of which were published in refereed journals and international conferences. Over 100 papers (from 32 refereed journals, 13 international conferences, and some other publications) have been reviewed. We identified thirty one different kinds of manufacturing systems that have been described as having the capability to deal with change. One representative reference was selected for each of the thirty one manufacturing systems as shown in Table 1. Manufacturing paradigms examined in this study were derived from a qualitative analysis of characteristics shared among thirty one different kinds of manufacturing systems. From this, four important manufacturing paradigms can be concluded: (1) Autonomy, (2) Distribution, (3) Modularity, and (4) Integration, which were associated with eight or more of the manufacturing systems (Wang, Cao and Ma, 2005; Cao, Wang, and Sun, 2005). Other manufacturing paradigms that were associated with fewer types of manufacturing systems are not considered in this paper. These four manufacturing paradigms are explained as follows.

(1) Autonomy Manufacturing Paradigm

An autonomy manufacturing paradigm means dealing with change through autonomous actions and autonomous control in manufacturing. It makes the entities in manufacturing systems, such as workers, work teams, have a capability to create and control the execution of their own plans and/or strategies. This paradigm employs local autonomy, in other words the decentralization of authority, which is necessary when the complexity of a manufacturing system increases, together with uncertainty in local decision-making (Villa, 2002). Accordingly, this paradigm suggests a new structure for dealing with change: a conglomerate of autonomous and distributed units, which operate as a set of cooperating entities (Monostori et al., 1998; Tharumarajah et al., 1996). Fourteen out of the thirty-one manufacturing systems examined in this study adopted an autonomy paradigm: intelligent manufacturing, holonic manufacturing, fractal factory, bionic manufacturing, random manufacturing system, genetic manufacturing, agent-based manufacturing system, interactive manufacturing, responsibility-based manufacturing, agile manufacturing, distributed networked manufacturing, modular production, flexible integrated manufacturing, and lean production.

(2) Distribution Manufacturing Paradigm

A distribution manufacturing paradigm means dealing with change through distributed structures and control systems. Distributed structures in manufacturing organizations make use of dispersed resources with flexible organizations and distributed control systems. A typical distributed structure is a networking organization, which involves a wide perspective covering geographic dispersion and interdependent coordination rather than the traditional focus on separated manufacturing sites (Shi and Gregory, 1998). Seven manufacturing systems use a distributed structure for dealing with change: agile manufacturing, contract manufacturing, distributed networked manufacturing (networked manufacturing, or remote manufacturing), information based manufacturing, Internet-based manufacturing, shared manufacturing, and international manufacturing networks. Distributed control is the other aspect of this paradigm, and is often associated with autonomous actions in manufacturing systems. An additional eight manufacturing systems use a distributed control: intelligent manufacturing, holonic manufacturing, fractal factory, bionic manufacturing, random manufacturing system, genetic manufacturing, agent-based manufacturing system, and interactive manufacturing.

(3) Modularity Manufacturing Paradigm

A modularity manufacturing paradigm means dealing with change through breaking down manufacturing systems or products into discrete pieces or units, which can communicate with one another only through standardized interfaces within a standardized architecture (Langlois, 2002). Components of manufacturing systems, such as pieces of equipment and subsystems, can be regarded as discrete pieces or units. Nine manufacturing systems utilize this approach: random manufacturing, agent based manufacturing, agile manufacturing, reconfigurable manufacturing, modularity production, holistic model-driven manufacturing, flexible integrated manufacturing, virtual cell manufacturing, and lean production. In addition, modularity characteristics can be also found in product design, which allows the decoupling of process for developing new products, enabling those processes to become concurrent, autonomous and distributed and making possible the adoption of modular organization designs for product development (Sanchez, 1996).

	Manufacturing systems	Autonomy	Distribution	Modularity	Integration	References
1	Intelligent manufacturing	*	*		*	Kopacek, 1999
2	Holonic manufacturing	*	*			Tharumarajah et al., 1996
3	Fractal factory	*	*			Warnecke, 1979
4	Bionic manufacturing	*	*			Okina, 1993
5	Random manufacturing	*	*	*		Iwata et al., 1994
6	Genetic Manufacturing	*	*			Ueda, 1992
7	Agent based manufacturing	*	*	*		Cantamessa, 1997
8	Interactive manufacturing	*	*		*	Ueda et al., 1998
9	Responsibility-based manufacturing	*			*	Adamides, 1996
10	Agile manufacturing	*	*	*	*	Yusuf et al., 1999
11	Contract manufacturing		*			Chan and Chung, 2002
12	Distributed networked manufacturing	*	*			Cheng et al., 2001
13	Information-based manufacturing		*		*	Shaw, 2000
14	Internet-based manufacturing		*		*	Tian, 2002
15	Shared manufacturing		*			Bidanda et al., 1993
16	International manufacturing networks		*			Shi and Gregory, 1998
17	Reconfigurable manufacturing			*	*	Koren et al., 1999
18	Modular production	*		*		Rogers and Bottaci, 1997
19	Holistic model-driven manufacturing			*	*	Weston, 1998
20	Flexible integrated manufacturing	*		*	*	Song, 2001
21	Virtual cellular manufacturing			*		Saad, 2003
22	Computer integrated manufacturing				*	Li and Li, 2000
23	Virtual manufacturing				*	Iwata et al., 1997
24	Learning manufacturing				*	Westkämper, 1996
25	Human centered manufacturing				*	Eichener, 1996
26	Anthropocentric production				*	Wobbe, 1994
27	Millennium manufacturing				*	Parnaby, 1997
28	Ultimate manufacturing				*	Wah, 1999
29	Life-cycle manufacturing				*	Westkämper et al., 2000
30	Post-mass production				*	Tomiyama, 1997
31	Lean production	*		*	*	Shah and Ward, 2003

Table 1 Manufacturing paradigms and manufacturing systems

(4) Integration Manufacturing Paradigm

An integration manufacturing paradigm means dealing with change through integrating different manufacturing processes and integrating human and technology in manufacturing systems. The integrative devices are often used to increase the chances for success when organizations face a changing and uncertain environment (Rondeau, 2000). The objectives of integration include several kinds, such as human-machine integration, integration of components of systems, and integration of components of business process (Kosanke and Klevers, 1990). Among them, two kinds of integration have been widely used in manufacturing systems: Integration of Process (IOP) and Integration of Human and Technology (IHT). Manufacturing activities, such as design, fabrication, and assemble, can be integrated together by using information technology. Computer integrated manufacturing (CIM) and virtual manufacturing are typical manufacturing systems for using the integration approach. With the sources of change and uncertainty expanding, Integration of Process needs to integrate more activities in the life cycle of a product, such as marketing and distribution. This idea can be found in two manufacturing systems: life-cycle manufacturing and post-mass manufacturing. Integration of Human and Technology puts organization and human competence in the forefront and requires adapted technologies. It is economically very successful in industrial sectors affected by steadily changing demands, volatile markets and the need for high adaptability to customer requirement (Eichener, 1996). This manufacturing paradigm is adopted in five manufacturing systems: learning manufacturing, human-centered manufacturing, anthropocentric production, millennium manufacturing, and ultimate manufacturing. In addition, many other manufacturing systems also adopted the integration approach, including intelligent manufacturing, interactive manufacturing, responsibility-based manufacturing, agile manufacturing, information-based manufacturing, internet-based manufacturing, reconfigurable manufacturing, holistic model-driven manufacturing, flexible integrated manufacturing, and lean production.

The relationships between the four manufacturing paradigms and thirty one manufacturing systems are summarized in Table 1. Asterisks in the table indicate strong relationships between the manufacturing systems in the rows and the manufacturing paradigms shown in the columns.

Item Generation

Business strategy and competitive priorities have been widely studied. Therefore, potential items for measuring them can be adopted from traditional literatures.

Business strategy has been widely studied as variants of generic strategies involving a choice between differentiation and delivered cost or price, and there is an instrument for making the generic strategic types operational, which has also been used frequently in strategic researches (Ward and Duray, 2000). We adapt the instrument to measure the price and differentiation aspects of business strategy in this paper. The measurement scales for these two types of business strategy can be found in Table 2. Respondents are asked to indicate the degree of emphasis on some activities as listed in Table 2 with a scale ranging from 1 to 5, where a response of 1 indicates no emphasis and 5 indicates extreme emphasis.

Measurement scales for the competitive priorities were also adopted from traditional studies. Their conceptions used in this paper and related explanations are given as follows. (1) The flexibility scale is intended to capture the importance of reducing costs associated with changing products or mix. This type of flexibility has two aspects: range and time, while the cost of providing flexibility is sometimes used as a third aspect. The range aspect signifies the extent of product variety, and the temporal aspect reflects setup time (Gerwin, 1993). (2) The quality scale includes items related to the important quality aspect of process control and process management, which can be used strategically to gain competitive advantage. (3) The delivery scale includes emphasis on customer service as indicated by either delivery reliability or delivery speed. (4) The cost scale includes emphasis on reducing production costs, inventory and increasing capability and equipment utilization. Ward and Duray (2000) provided an instrument to make the four competitive priorities operational. Their instrument was adapted in this study with some modifications, for example using a five-point Likert scale instead of a seven-point Likert scale. Respondents are asked to indicate the degree of emphasis on some activities as listed in Table 3 with a scale ranging from 1 to 5, where a response of 1 indicates no emphasis and 5 indicates extreme emphasis.

Variables	Measurements scale items
Business strategy	
Price	Operating efficiency
	Competitive pricing
	Procurement of raw materials
	Reducing product costs
	Minimize outside financing
	Decreasing the number of product features
Differentiation	New product development
	Brand identification
	Innovation in marketing techniques and methods
	Control of distribution channels
	Advertising
Competitive priorities	
Flexibility	Lead-time reduction
	Setup time reduction
	Ability to change priorities of jobs on the shop floor
	Ability to change machine assignments of jobs on the shop floor
Quality	Statistical process control
	Real-time process control systems
	Updating process equipment
	Developing new processes for new products
	Developing new processes for old products
Delivery	Provide fast deliveries
	Meet delivery promises
Cost	Reduce inventory
	Increase capacity utilization
	Increase equipment utilization
	Reduce production costs

Table 2. Potential items for measuring business strategy and competitive priorities

Measurement scales for the manufacturing paradigms are explained as follows. (1) The measurement scales of the autonomy paradigm were developed based on the definitions of autonomous actions and the characteristics of related manufacturing systems. The existence of autonomous actions in operation management implies that managers below the top management level can make decisions with strategic implications without prior approval from top management (Andersen, 2000). (2) The measurement scales of the distribution paradigm were developed based on the definition and the characteristics of related manufacturing systems. The distribution paradigm can be used both in controlling systems and in organization structures of manufacturing systems, and we focus on the latter.

Modularity		
Modularity Through Fabrication	MTF1	Components are designed to end-user specifications
	MTF2	Components are sized for each application
	MTF3	Components are altered to end-user specifications
	MTF4	Component dimensions are changed for each end-user
Modularity Through Standardization	MTS1	Products have interchangeable features and options
	MTS2	Options can be added to a standard product
	MTS3	Components are shared across products
	MTS4	New product features are designed around a standard base unit
	MTS5	Products are designed around common core technology
Distribution		
	DIS1	Geographic dispersion
	DIS2	Linked by networks
	DIS3	Sharing resources (human resources, equipments, etc.) with other subsidiaries
Autonomy		
	AUT1	Managers below the top management level can make decisions with strategic implications without prior approval from top management.
	AUT2	Machines have replaced many human workers
	AUT3	Workers in the job shop can manage themselves and have power to make some decisions
	AUT4	Different departments can cooperate and support each other
Integration		
Integration Of Process	IOP1	Integrated closely within your own organization
	IOP2	Integrated closely with raw material suppliers
	IOP3	Integrated closely with distributors/retailers
	IOP4	Integrated closely with customers
	IOP5	Keep good cooperation relationships with other firms
	IOP6	Emphasize cooperation between different departments
Integration of Human and Technology	IHT1	Machines have been closely integrated with human and emphasize human factors engineering
	IHT2	Human resources has been regarded as the most important asset
	IHT3	Knowledge management has been emphasized
	IHT4	Different methods or technology can be adopted according to needs
	IHT5	Education and training is an important function
	IHT6	Keeping good relationships with consulting companies

Table 3. Potential items for measuring the manufacturing paradigms

(3) The measurement scales of the modularity paradigm in this paper focus on product design and manufacturing. The modularity paradigm in the design of manufacturing systems is not investigated since firms infrequently undertake reengineering of entire manufacturing systems. Duray et al. (2000) proposed two methods to realize the modularity paradigm in manufacturing, i.e.,

Modularity Through Fabrication (MTF), which is characterized as cut-to-fit and component sharing; and Modularity Through Standardization (MTS), which is characterized as component swapping, sectional, mix, and bus modularity. We adapt the instrument provided by Duray et al. (2000) to measure Modularity Through Fabrication as well as Modularity Through Standardization in this study. (4) Both types of the integration paradigm were measured. Their measurement scales also were developed based on literatures and the characteristics of related manufacturing systems, such as instruments for measuring integration in the supply chain (Rosenzweig et al., 2003). For the manufacturing paradigms, survey respondents were asked to indicate the degree to which the measurement scale items are current concerns to their firms. All items are represented by a five-point Likert scale of 1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly Agree, and NA=Not Applicable or Do Not Know.

Methodology for Measuring Paradigms and Testing Hypotheses

The measurement scales of business strategy and competitive priorities were adapted from traditional studies and have been validated. Therefore, we only test the vertical validity of them in this paper with Cronbach's Alpha. Measurement scales of the four manufacturing paradigms were developed in this paper. Therefore, it is necessary to test their construct validity and reliability. In this study, the basis for theoretical validity was established through the review of a larger body of literatures. Vertical validity is addressed via Cronbach's alpha. In addition, factor analysis is used to further check that each of the scales is unidimensional, thus providing evidence of a single latent construct (Roneau, 2000).

Totally, there are five steps to set up the measurements of the manufacturing paradigms. The first step is to purify the items based on Corrected Item Total Correlation (CITC). As a guideline, items with a value of CITC below 0.50 were eliminated. The item inter-correlation matrices provided by SPSS were also utilized to drop items, if they did not strongly contribute to Cronbach's alpha. Secondly, items related to a specific approach were submitted to exploratory factor analysis to assess the dimension's internal consistency. The principal components approach was selected for the extraction procedure, with the varimax method used for factor rotation. The MEANSUB command was used within SPSS to replace the very small number of missing values with the mean for that item. Items that did not load at 0.60 or above were eliminated unless those were considered to be important for the research. The adequacy of the sample size for factor analysis was calculated using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy. In this study, items that had weak factor loadings were designated for modification if their content was considered important to the research. This is consistent with the recommendation that the researcher consider an item's importance to the research as well as its loading during factor interpretation. Thirdly, Structural equation modeling (SEM) was used to make further refinement possible for the measurement of the approaches. The reason is that factor analysis assumes that measurement errors are not correlated, and it does not test the degree of correlation of these error terms. Structural equation modeling does test the degree of correlation among the error terms. Model evaluation criteria of SEM were explained in the following paragraph. Items were dropped with path coefficients less than 0.60 until the measurement model getting a good performance and all path coefficients above

0.60. Fourthly, the external consistency of manufacturing paradigms was evaluated by submitting simultaneously the items for all paradigms to exploratory factor analysis. No constraint was placed on the number of factors that could emerge. The method of extraction was principle components with varimax rotation. Items that did not load at 0.60 or more were usually eliminated. At last, the reliability of the remaining items was assessed using Cronbach's alpha.

AMOS (Analysis of MOment Structure), package software of the SEM, was used to set up the measurement models for business strategy, competitive priorities, and manufacturing paradigms, and the structure models for the relationships between them. For model evaluation, several standard criteria were used (McKone et al., 2001). (1) The Degree of Freedom (DF) represents the difference between the number of independent statistics and the model parameters fitted. (2) The Likelihood Ratio Test (LRT) statistic is minimized and is usually interpreted as a X^2 variety. (3) The probability level in chi-square testing should be higher than 5% level. (4) Goodness of Fit Index (GFI), (5) Adjusted Goodness of Fit Index (AGFI), and (6) Comparative Fit Index (CFI) rescale the fit of the observations and the expectations. Values of GFI, AGFI, and CFI between 0.80 and 0.89 represent a good fit while values above 0.90 represent a very good fit. (7) Root mean square error of approximation (RMSEA) is a measure of the population discrepancy that is adjusted for the DF for testing the model. A value of 0.08 or less for RMSEA would indicate a reasonable error of approximation. If the model fits the data well, the magnitude of the AMOS path coefficients can be examined for statistical significance. The test for significance compares the estimated parameter to its standard error and has a t-distribution.

Survey Methodology and Sample Characteristics

The relationships between business strategy, competitive priorities, and the manufacturing paradigms were surveyed with a questionnaire. The survey data was collected through structured interviews with managers of manufacturing firms in the People's Republic of China. As the world's fourth-largest industrial producer behind the United States, Japan and Germany, the country of China makes more than 50% of the world's cameras, 30% of the world's air-conditioners and televisions, 25% of the world's washing machines, and nearly 20% of all refrigerators (Leggett and Wonacott, 2002). Four universities in four different regions of China were involved in carrying out the survey. The study regions were Beijing City in the north of China; Shanghai City in the east; Wuhan City in the center; and Xi'an City in the west of China. About five graduate students from each university took part in the data collection process and were trained in using a consistent interviewing method. The surveys were initiated in November 2003, and completed in January 2004.

To assure accuracy and completeness of responses, the survey data was collected through structured interviews with a purposeful sample of 118 firms. These firms were selected through the recommendations of the local university as being leading manufacturers and represented a variety of manufacturing industries. From each firm, we interviewed a person with responsibilities for manufacturing management, mostly general managers or department managers. From this, we obtained 107 completed questionnaires used in the analysis. The sample demographics are shown in Table 4. The size of the firms ranges from around 20 employees to over 1,000 employees. The gross sales in these firms vary from less than 2.5 million to over 500 million dollars. The most commonly manufactured products are machinery, computers, air conditioners, and electronic equipment.

Characteristics of firms		Number of firms	Percent of total (%) (N=107)
Number of Employees	<21	6	5.6
	21-50	9	8.4
	51-100	11	10.3
	101-200	15	14.0
	201-500	12	11.2
	501-1000	13	12.1
	>1000	41	38.3
Gross Sales (US$ in millions)	2.5	20	18.7
	2.5-15	27	25.2
	15-30	20	18.7
	30-60	4	3.7
	60-120	11	10.3
	120-250	9	8.4
	250-500	11	10.3
	>500	5	4.6
Location	Beijing City	30	28.0
	Wuhan City	31	29.0
	Xi`an City	9	8.4
	Others	37	34.6
Representa -tive Items Produced	DVD players, Apparel, Silk fabric, Car, Electronic equipment, Beer, Medicine, Motors, Hydraulic systems, Elevators, Display screens, Air conditioners, Capacitors, Television components, Chemicals Industrial sewing machines, Washing machines, Laser equipment, Communications equipment, Computers, Computer peripherals, Capacitor thin film, Cameras		

Table 4. Description of firms in samples

MEASUREMENT RESULTS

This section reported the results of measurement of the manufacturing paradigms. Two types of modularity paradigms (MTS and MTF) and integration paradigms (IOP and IHT) were measured respectively. Initially, six manufacturing paradigms, i.e., AUT, DIS, MTF, MTS, IOP, and IHT, were measured with twenty-eight scales as shown in Table 3.

Purification

One original scale of the autonomy paradigm (AUT2) and one original scale of Modularity Through Fabrication (MTF2) were eliminated because of low CITC scores. Some original scales with CITC score less than 0.50 are keep for following analyses because they are important for the research and their scores are also close to 0.50.

Dimension-level Factor Analysis

In the factor analysis of each approach, a single factor emerged for everyone with all item loadings greater than 0.60 except for the IHT1 in the approach of

Integration of Human and Technology. Therefore, IHT1 was dropped. The KMO measure for each construct indicates that factor analysis was possible.

Single factor measurement models are specified for the six approaches with AMOS. Results show that AMOS measurement models for all approaces except for Modularity Through Standardization satisfied the requirements. Measurement models of the distribution paradigm and the autonomy paradigm have one path coefficient less than 0.60. We keep them for the following analysis, because that they are important for this research and very close to 0.60. Some estimate criteria for the measurement model of Modularity Through Standardization are much below than the recommended minimum level, indicating that further modification may be required. Modification indices (error correlation between items) and path coefficients are used to suggest for iterative modifications to improve key model fit statistics. At last, MTS 4 and MTS 5 were dropped from the measurement of Modularity Through Standardization.

	Factors loadings above 0.50 (KMO=0.85)					
Item	F1-IOP	F2-IHT	F3-MTF	F4-DIS	F5-MTS	F6-AUT
IOP1	0.669					
IOP2	0.768					
IOP3	0.645					
IOP4	0.608					
IOP5	0.737					
IOP6	0.726					
IHT2		0.602				
IHT3		0.678				
IHT4		0.608				
IHT5		0.716				
IHT6		0.738				
MTF1			0.763			
MTF3			0.819			
MTF4			0.838			
DIS1				0.771		
DIS2				0.729		
DIS3				0.621		
MTS1					0.761	
MTS2					0.798	
MTS3					0.760	
AUT1		0.508				0.536
AUT3						0.832
AUT4						0.881
E.V.	3.91	3.11	2.22	2.08	2.07	1.95
P.V.	17.02	13.50	9.64	9.05	9.00	8.46
C.P.V.	17.02	30.52	40.16	49.20	58.21	66.66

Table 5. Factor loadings for the construct analysis

Construct-level Factor Analysis

Remaining items were submitted to factor analysis. Six factors emerged, as shown in Table 5. Factor loadings above 0.50, eigenvalue (E.V.), percentage of variance (P.V.), and cumulative percentage of variance (C.P.V.) were listed. Considering the loadings above 0.60, the first five factors can be identified as following, i.e., F1-IOP (Integration Of Process), F2-IHT (Integration of Human and Technology), F3-MTF (Modularity Through Fabrication), F4-DIS (Distribution), and F5-MTS (Modularity Through Standardization). The item of AUT1 has loadings above 0.50 on F2 and F6, and both loadings are less than 0.60. With regarding to the loading of AUT1 on F6, which is higher than the loading of AUT1 on F2, and the importance of AUT1 to F6, we identified F6 as AUT (Autonomy) and did not drop AUT1. At last, no items were dropped in this step. These factors explain 66.66% of the variance. The KMO measure indicates that factor analysis was possible.

Reliability
Inter-item analysis is used to check the scales for internal consistency for reliability, which is satisfied in this study. Specially, Cronbach's reliability coefficient alpha is calculated for each approach, i.e. 0.86 (F1-IOP), 0.86 (F2-IHT), 0.76 (F3-MTF), 0.65 (F4-DIS), 0.70 (F5-MTS), and 0.71 (F6-AUT). Inter-item analysis is also conducted on business strategy and competitive priorities, which is also satisfied in this paper. The Cronbach's reliability coefficient alpha is shown in follows: 0.68 (cost leadership), 0.83(differentiation), 0.68 (flexibility), 0.74 (quality), 0.74 (delivery), and 0.76 (cost).

RESULTS FOR STRUCTURAL MODELING
Higher-orders measurement models were set up for the manufacturing paradigms, since the modularity paradigms and integration paradigms have two kinds. In order to test the hypotheses, different structure models were set up according to different hypotheses in AMOS 4.0. Model B is shown in Figure 4. It regards that the competitive priorities and the manufacturing paradigms have direct relationships with business strategy, but there are not direct relationships between the competitive priorities and the manufacturing paradigms. In model A as shown in Figure 5, business strategy has direct links with the competitive priorities, which has direct link with the manufacturing paradigms, and there is no direct link between business strategy and the manufacturing paradigms. In model C as shown in Figure 6, both the competitive priorities and the manufacturing paradigms have direct relationships with business strategy, and there is a direct link between them.

The performances of these three models are shown in the following Table 6. As we can find that model B has the highest value in GFI, AGFI, and probability level. All three models had same RMSEA values. According to Byrne (2001), whether the difference between different models is statistically significant can be tested based on χ^2 statistics. A necessary condition is that two models should be nested, which means two models are hierarchically related to one another in the sense that their parameter sets are subsets of one another. Under this condition, "the differential between the models represents a measurement of the over-identifying constraints and is itself χ^2 distributed, with degree of freedom equal to the difference in degrees of freedom; it can thus be tested statistically, with a significant $\Delta\chi^2$ indicating substantial improvement in model fit" (Byrne, 2001). There are nested relationships between mode A and model C, and between model B and model C. Based on the difference between the values of χ^2, we can find following results:

(1)There are significant difference between model A and model C. The $\Delta \chi^2$ (M.A-M.C) is 5.897, which is significant in χ^2 (DF=1, P<0.05).

(2) There are no significant difference between model B and model C. The Δ χ^2 (M.B-M.C) is 0.004, which is not significant in χ^2 (DF=1, P<0.05).

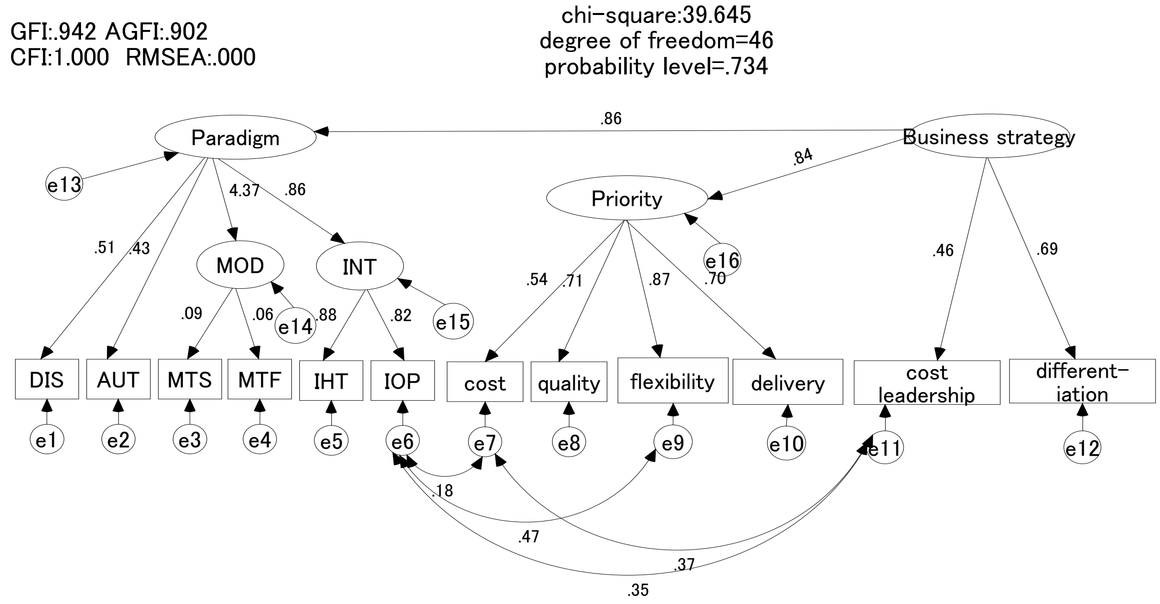


Figure 4 A current model with two ways (model B-hypothesis 2)

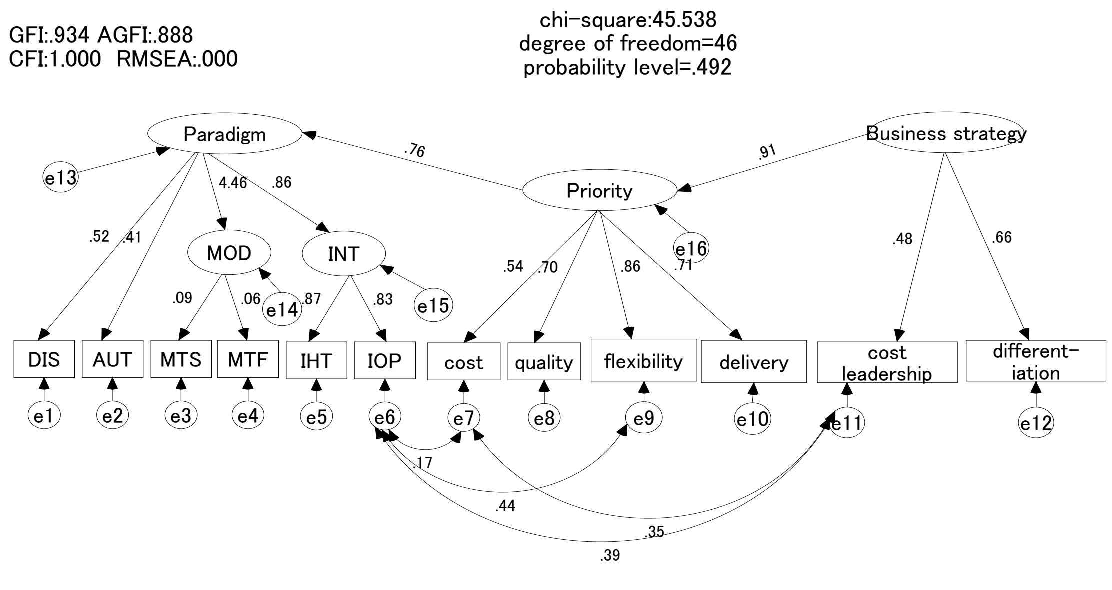


Figure 5 A serial model with one way (model A-hypothesis 1)

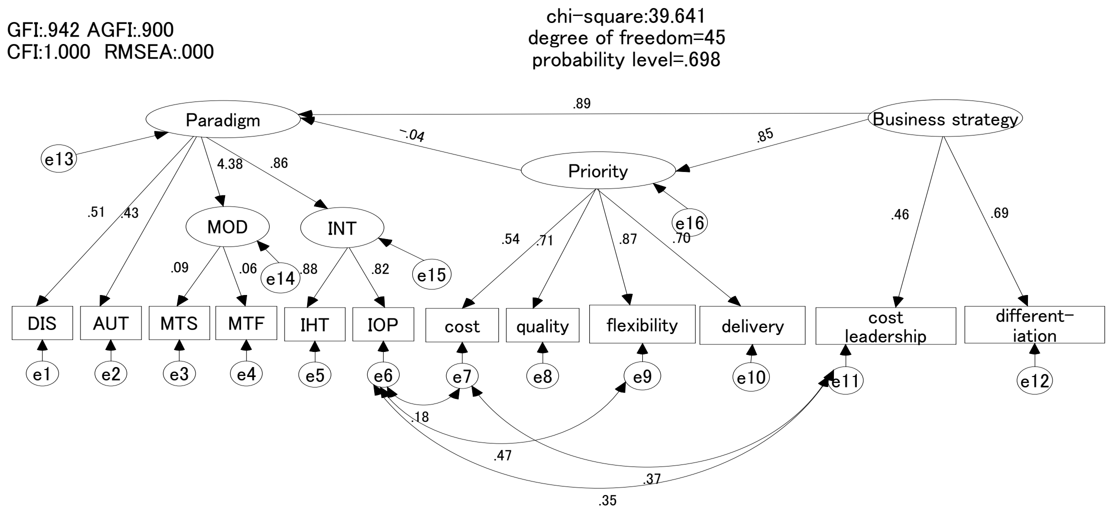


Figure 6 A completed model with two ways (model C-hypothesis 3)

Criteria	Model A	Model B	Model C	Standard
GFI	0.934	0.942	0.942	[0,1]
AGFI	0.888	0.902	0.900	[0,1]
CFI	1.000	1.000	1.000	[0,1]
RMSEA	0.000	0.000	0.000	<=0.08
LRT/DF	0.990	0.862	0.881	<=5

Table 6 Performances of three models

Therefore, we can conclude that model B and model C have significant difference with model A in the performance. Then, we can pay attention to the path coefficients in model B and model C. The model C has good performance, however, the path coefficient between manufacturing paradigms and competitive priorities in model 3 is -0.04, which is not significantly different from zero at the significant level 5% (two-tailed). On the other hand, both of the two path coefficients in model B are significantly different from zero tested by T statistics. Therefore, the results of models C are supporting the structure in model B. At last, we can explain our results based on model B.

When the modification indices were examined for the model A based on model B, the indices suggest that a relationship exists between business strategy and the manufacturing paradigms. When the modification indices were examined for the model C based on model B, the indices suggest that a relationship does not exist between the competitive priorities and the manufacturing paradigms if both competitive priorities and the manufacturing paradigms are connected to business strategy. The results of the model B support Hypothesis 2, which claims that manufacturing paradigms has direct relationships with business strategy. The path coefficient is 0.86, where the statistics significant at level $P<0.001$ ($t=3.32$). The path coefficient between business strategy and competitive priorities is 0.84, which is also significant at level $P<0.001$ ($t=4.17$). The result of the model B does not support Hypothesis 1, which claims that manufacturing paradigms can be linked to business strategy through competitive priorities. The result of model B does not support the hypothesis 3, too.

DISCUSSION AND CONCLUSION

The results in this study show that under the turbulent environment business strategy has direct influence on the decisions on manufacturing paradigms, and competitive priorities can not underlay the media roles between business strategy and manufacturing paradigms. When planning MS, we may adopt the strategic approach and the paradigmatic approach, and make the decisions on competitive priorities and manufacturing strategy based on business strategy respectively. The results can be explained by the effectiveness of the two approaches, and can also give some suggestions for planning manufacturing strategy under the turbulent environment.

It is possible to adopt two approaches for planning manufacturing strategy at the same time, though there are some differences between them. Most manufacturing strategy models are based on the strategic approach, but it does not preclude the possibility that competitive advantage from manufacturing may also generated from unplanned patterns of activities rather than a strategic plan. When Ward et al. (1990) proposed a top-down hierarchical process model for manufacturing strategy, they also admired that an argument should be considered. According to the argument, "the process model should be revised for currently development of conventional strategic planning activities along with capability building activities such as 'Totoal Quality Control'". Recently, Spina (1998) provided some empirical evidence to support the compatibility of the two perspectives on manufacturing strategy. Clark (1996) and Hayes and Pisano (1996) suggested that these two perspectives can be explained with one framework, where decisions, such as adoption of more flexible production equipment, make firms' performance change in the same performance frontier, and decisions, such as adoption of Lean Manufacturing, make firms' performance change between different performance frontiers. Suggested by Clark (1996), firms should integrated the AMS implementation and traditional manufacturing strategy prescriptions, rather choose between them. Our research supports the current development of two different approaches for manufacturing strategy, and further examined how to do it in detail. On the other hand, it is also necessary to currently adopt two approaches for planning manufacturing strategy in the turbulent environment. One important reason is that the media effects of competitive priorities in the planning process of manufacturing strategy are facing some challenges under the turbulent environment. The most important challenge to the planning of manufacturing strategy is not how to compete on cost, quality, delivery, or flexibility, but how to quickly response the changes in the requirement of competition. Therefore, the media effect of competitive priorities in the turbulent environment cannot reflect the core requirement in the competition. With the changing competitive environment, several studies regard that "strategic analysis should shift their attention from industry forces and product market positioning to developing and exploiting the unique set of resources" (Hayes and Pisano, 1996). From the manufacturing strategy side, building basic internal capabilities becomes more important than achieving specific market or financial goals (Hayes and Pisano, 1996). The paradigmatic approaches are good choices for firms to realize the purposes.

We focus on the manufacturing paradigms in the turbulent environment. Through concluding the characteristics of dealing with change in thirty one different kinds of manufacturing systems, four important manufacturing paradigms were identified: autonomy, distribution, modularity, and integration. These manufacturing paradigms are important for the operationalization of paradigmatic approach in the turbulent environment. However, these paradigms focus on the capability of dealing with changes and can not satisfy all requirements in different competitive environments. Further studies are needed to focus on the identification of manufacturing paradigms in different environment. Furthermore, we tested the relationships based on the samples only from the People's Republic of China, an important line of the future research is to test the stability of the relationships globally, and over time.

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Chinese ICT Industry from Supply Chain's Perspective

– A case study of the major Chinese ICT players

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Abstract

The Information and Communication Technology (ICT) came forth in the middle of the 20th century. During its no more than 20 years' development, the ICT industry has been fleetingly aggrandizing. The research concerning the emergence and development of the ICT industry then becomes current and subservient. Asia, especially China plays a significant role within ICT segment since it has become a major supplier for the ICT industry and meantime it has a large customer market that is growing very fast compared to every other market area in the world.

The paper is based on the interviews carried out in July 2006 with ten important Chinese ICT companies. The essential finding of this paper is that the Chinese operators are the focal companies within the Chinese ICT supply network, which is verified by the alliance analysis using UCINET software. Besides, the supply chain business processes of the Chinese ICT industry are also revealed, but the verifying of the business processes needs to be further studied.

1. Introduction

ICT (information and communication technology) sector has had an enormous growth during recent years. The continuously increasing use of VOIP (voice over Internet protocol) technology, for example the Nordic invented Internet based telephony Skype, is impacting the traditional telecommunication industry. In addition, there appear of various value-added services around mobile telecommunication, for example short message service (SMS), multimedia message service (MMS), mobile gaming and mobile TV. It indicates that IT (information technology) industry, CT (communication technology) industry and even the media industry have a tendency to be merged into one unique business entity, ICT. ICT has been greatly penetrating into our daily life, not only for the individual consumers, but also for the managing of the enterprises and even the governments. Therefore the research of ICT industry appears to be crucial.

ICT sector has fostered the growth of several developed and developing regional areas. One of the most attractive single regional areas includes China and its evolving supply chain network. OECD (2004) indicates that the production of ICT goods and ICT-related services are shifting towards Asia and China. For instance, Global Sources (2006) records that, according to the statistic from the China Custom, the number of the exported mobile handsets from China in 2005 reaches 228 million and the exported sum exceed 16.1 billion EUR. Compared with 2004, the growth of the exported mobile handsets and the exported sum from China are respectively 56% and 45.7%; China as the largest handsets manufacturing base in the world, the global market share of the China made mobile handsets has currently reached 33.3% ~ 50%. Illustrate with another example in Table 1, the key financial statements of the four most important operators in China convince as well how the ICT-related services develop in China.

	Key Financial Statements (2005-12-31)					
	Total Assets (Million €)	**5-Year Growth**	**Annual Sale (Million €)**	**5-Year Growth**	**Net Income (Million €)**	**5-Year Growth**
China Mobile	43 536	86.21%	25 258	85.52%	5 565	46.37%
China Netcom	20 944	-16.44%	9 056	37.36%	1 443	43.72%
China Telecom	42 676	69.75%	17 786	91.22%	2 932	213.94%
China Unicom	14 949	-13.19%	9 046	126.78%	512	-15.27%

Table 1. Major Chinese ICT Operators (Source: Thomson ONE Banker)

Further, the ongoing convergence development with various technologies and services from traditional telecommunication, media, information technology and Internet is changing the structure of global ICT supply chain network and therefore the research work of the supply chain within the Chinese ICT industry has been carried out.

The above background provides the motivation of current study. This study is part of the Finnish project "The Dynamics of the Value Creation in ICT Value Network", which started at the beginning of 2005. The main objective of this project is to create a complete view of how the value network (and entire business ecosystem) of ICT industry is formed and what are the changes that are about to happen in the future. Most of the work having been done concerns the value network of the global ICT industry.

In this study, we aim at analysing Chinese ICT value network from a different perspective, namely using the existing supply chain models to illustrate ICT network structure and describe its business processes. More specially, the purpose of this paper could be formulated into the following three questions:

- What are the typical characteristics of the Chinese ICT industry?
- What are the major driving forces and uncertainties that influence the development of the Chinese ICT industry?
- What are the future trends of the ICT industry in China?

By examining the ICT network structure, we can identify the role of each player and their interaction in the Chinese ICT Market. Following the supply chain business processes' approach, we expect to illustrate the general business processes in creating values in the Chinese ICT industry. This model can furthermore be used to predict the business activities after an innovative idea of ICT product(s) or service(s) was introduced and therefore it has a potential to forecast the product and process development in ICT industry

In section 2 and section 3, the literature framework as well as the method for data collection for this study are presented respectively. The Chinese ICT industry's supply network structure and supply chain business processes are addressed in section 4 respectively section 5. Section 6 gives out the future scenarios of the ICT industry in China; while in the last two sections the conclusions respective the possible opportunities for the future research are outlined.

2. Literature

In this section, the ICT industry is going to be scoped first. After that, the supply chain framework applied in this paper is outlined. The concept of alliance and Networks are introduced as well. The gap between the ICT industry and the supply chain framework is discussed at the end.

Defining ICT

The definition of ICT industry is not necessarily straightforward task. There are various angles to be considered, as for example Smith (2001) has declared: “The question here is not simply whether we can think of ICT as an industrial sector, or even a more or less unified industrial activity. It is also whether it makes sense to speak of ICT as a unified technology, or whether it is in fact many technologies, perhaps only loosely related to each other.” Gruber (2001) defines the Information and Communication Technology (ICT) sector as the technological convergence of the Information Technology (IT) and telecommunication technology.

Another definition of ICT sector, which we apply in this paper, is provided by Working Party on Indicators for the Information Society (WPIIS) in April 1998. This is also the base of OECD definition of ICT industry. WPIIS categorizes ICT industry into ICT manufacturing industry and ICT service industry. The respective definitions are:

- ICT manufacturing industry:
    - *must be intended to fulfil the function of information processing and communication including transmission and display;*
    - *must use electronic processing to detect, measure and/or record physical phenomena or to control a physical process*.
    - *Components primarily intended for use in such products are also included.*
- ICT service industry:
    - *must be intended to enable the function of information processing and communication by electronic means*.
    - *The service provided must go beyond simply the supply of goods.*

According to this definition, OECD (2005) defined ICT industries in 1998. Defined industries were amended again in 2002 to its current state, which are (according to OECD industry classification. The codes in the parentheses are SIC-codes):

- Manufacturing:
    - *Manufacture of office, accounting and computing machinery (3000)*
    - *Manufacture of insulated wire and cable (3130)*
    - *Manufacture of electronic valves and tubes and other electronic components (3210)*
    - *Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy (3220)*
    - *Manufacture of television and radio receivers, sound or video recording or reproducing apparatus, and associated goods (3230)*

- *Manufacture of instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment (3312)*
- *Manufacture of industrial process control equipment (3313)*

- Services:
    - *Wholesale of computers, computer peripheral equipment and software (5151)*
    - *Wholesale of electronic and telecommunications parts and equipment (5152)*
    - *Telecommunications (6420)*
    - *Renting of office machinery and equipment (including computers) (7123)*
    - *Computer and related activities (72)*

This division can be also illustrated, when it gives a better picture of the industry as a combination of several activities and their interfaces. Referring to the Fig.1, OECD proposes that "…the ICT Sector can be viewed as the activities which fall into the union of the Information Technology and Telecommunications activities in the diagram below. It includes therefore the intersections between them and the Information Content activities. However it excludes those Information Content activities which fall outside those intersections; that is, those which have no direct ICT association" (OECD, 2005).

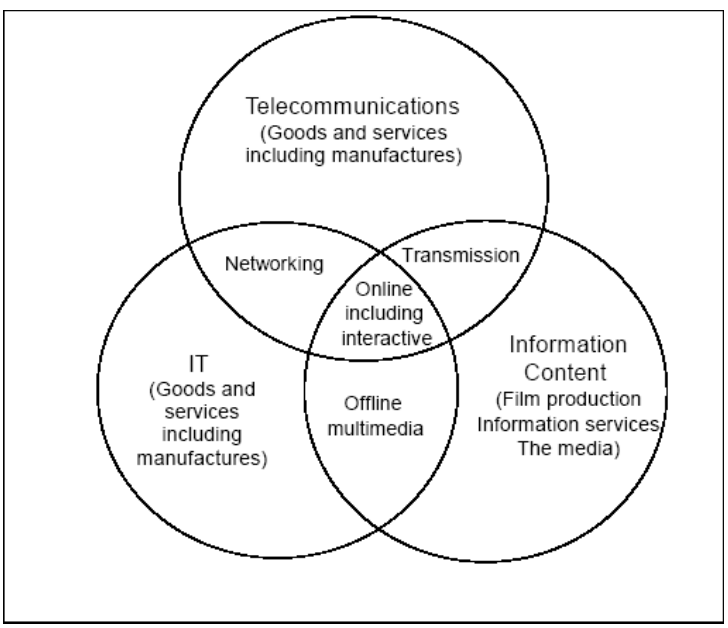

Fig.1. Overlap between the IT, Telecommunications and Information Content Activities of Firms (Adapted from a Finnish Model) (OECD, 2006)

Supply Chain Framework

Supply chain has been a keen topic both for the academia and the practitioners for a long time (Cousins et al., 2006). Christopher (1998) defines supply chain as *the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer*. The emphasis of this definition is the ultimate consumer, which is also the focus when identifying the supply chain business processes. In our viewpoint, the existing body of supply chain literature provides an additional platform to identify the role of players and the value adding process in ICT industry.

Due to its complexity, there are different models and approaches to describe supply chain. The supply chain management (SCM) framework presented by Lambert and Cooper (2000) fits very well our purpose in this study. According to their model, the three closely interrelated elements within the SCM framework are *the supply chain network structure, the supply chain business processes, and the supply chain management components*. This paper focuses on: the supply chain network structure and the supply chain business processes. Since this two elements are most important in understanding the ICT industry and each player's role at strategic level. The issue about supply chain management components is excluded in this paper, since the questions formulated for the research purpose are far beyond the operative level.

Supply chain, from the network structure's perspective, is *a society (a network of members, termed a group) formed by autonomous entities (and their systems) by bonding together to solve a common problem* (Chandra and Kumar 2001), which emphasis the common goal for the entire network of members. Two issues are often outlined regarding supply chain network structure: (1) the individual supply chain members and (2) the configuration of the supply chain members within the supply chain as well as their common objective.

One important change in managing supply chain is the emphasis on integrating activities into key supply chain processes instead of individual functions. For instance, in Lambert & Cooper (2000), the major business processes included customer relationship management, customer service management, demand management, order fulfilment, manufacturing flow management, procurement, product development and commercialization, and returns. A firm is organized around these processes and the ultimate focus of these business processes lie on meeting the customer's requirements (Cooper at al 1997). Therefore the supply chain business processes approach deserves to be studied. We adopt Cooper et al. (1997)'s definition of business processes in this study, *the activities that produce a specific output of value to the customer*. For our study, the customer within this context refers to as the one of the supply chain members outside ICT industry, end user.

Alliances and networks

It can be argued that industries emerge from networks of relationships with various interdependent organizations. Network analysis focuses on the relations among actors, and not individual actors and their attributes (Hanneman & Riddle, 2005). In this paper we emphasize the alliance relationships between organizations since a lot of inter-firm collaboration takes place in alliance relationships with actors in industry networks. According to Doz & Hamel (1998) alliance relationships differ from the traditional market transactions in that they can be characterized as strategic collaborative relationships with companies. They state that alliance relationships are essential in global competition since they allow the sharing of complementary resources between organizations. Furthermore, the inherent uncertainty in the business environment requires the formulation of alliances and collaborative learning processes. Recent alliance research has indicted that firms are utilizing strategic alliances in the execution of specific business strategies (Yasuda & Iijima, 2005). It follows that the exploration of structural position in industry alliance network is about to provide interesting insights to the strategic positioning of the companies in an industry level.

Gaps between ICT and Supply Chain

However, the contextual focus of supply chain is mostly related to manufacturing (Burgess et al., 2006). Although there are also a lot of papers using supply chain framework to deal with manufacturing issues in ICT industry, for example, electronics (Berry 1994), mobile infrastructure (Collin & Lorenzin 2006), mobile handsets (Olhager et al. 2002, Catalan & Kotzab 2003), risk management of the telecommunication manufacturing segment (Agrell et al. 2004, Norrman & Jansson 2004), there are little literature describing the entire ICT industry including service sector from supply chain's perspective. Kemppainen & Vepsäläinen (2003) present some interesting themes for both academia and practitioners, one of them is *the industrial scope of supply chain*. Our study is going to focus on the industrial scope of supply chain regarding the entire ICT industry.

3. Methodology and Data Collection

In this section, the methodology and limitations, selection of the interviews as well as the interview frameworks of this study are going to be described respectively.

Methodology and Limitations

The major data of this study comes from the interviews with some representative Chinese ICT players. The interviews were carried out in China in July 2006. There were ten interviews and the average time for each interview was 3 hours. The interviews were documented and transcribed for analysis.

Hallikas et at. (2005) categorize the different roles within the ICT industry in the ICT value network, which is illustrated in Appendix. For the categorization we pre-studied the specific situation for the Chinese ICT industry before the interviews and condensed the categorization by Hallikas et al. (2005) to five key categories, **Equipment Provider** (**EP**), **Application Provider** (**AP**), **Service Provider** (**SP**), **Content Provider** (**CP**) and **Operator**, which are attributed to as **Supply Chain Members within ICT Industry**. The **Supply Chain Members outside ICT Industry** includes **Regulator**, **End user** and **Intermediary**. The major functions of these supply chain members are listed in Table 2 and these supply chain members are detailed described in section 4. One thing is worth mentioning here that, for the supply chain members within ICT industry, the EP some time acts also as AP, while the SP often covers what the CP does. Therefore we note them as EP/AP and SP/CP in this paper.

For the time being and for the business secrecy, the interviews cannot be conducted into deeper extend. The supply chain members cannot be divided into more detailed level nor can some of the quantitative data be collected or published. But this does not affect the presented results in this paper. On the other hand, this research has a geography limits within the China mainland, which does not include Hong Kong, Macau and Taiwan. Hong Kong, Macau and Taiwan have their special policies and situations in their ICT industry, which could be studied individually.

Supply Chain Members		**Functionality**
Within ICT Industry	**EP**	Providing equipments: network infrastructure, handset etc.
	AP	Providing applications: software etc.
	SP	Providing service platforms
	CP	Providing content: music, pictures, mobile games, etc.
	Operator	The government authorized to own the basic network infrastructure, through which the various services (voice services, value-added services) can be provided to the end users.
Outside ICT Industry	**Regulator**	The organization to constitute the various industrial regulations.
	End User	Ultimate customers who consume the devices and various services.
	Intermediary	Selling the handsets or SIM-cards to the customers.

Table 2. The Categorization of the ICT Supply Chain Members

Selection of Interviews

Because of the time and resource limitation, the criteria for the selection of the interviewed companies become essential to the interviews. The following three aspects are considered within the company selection procedure:

- Selection of the **geographical regions**. There are three most important regions in china concerning the ICT industry, Pearl River Delta Area, Yangtze River delta Area and Bo Sea Gulf Area. Pearl River Delta Area is the high-tech area for ICT industry with the largest scale, the fastest developing speed and the highest proportion of exporting within China. The focal products within this area include telecommunication equipments, PCs and basic components etc. Yangtze River Delta Area, with Shanghai as its centre, is major in producing laptops, PDAs (Personal Digital Assistant), mobile handsets and electronic fittings etc. The competence of the Bo Sea Gulf Area lies in the research and development (R&D) of the IT industry. For example Beijing, the centre of the Bo Sea Gulf Area, has a lot of universities or colleges which provide the resources for the technology research. The interviewed companies are therefore limited in these three areas.

- Selection of the **interviewed company**. As mentioned in section 2, the supply chain members within the ICT industry include five sectors: EP/AP, SP/CP and operator. It should have at least one example company from each of the five sectors. A company selection also depends on its size and importance for the industry. One of three forces that cause the changes within business models foe ICT industry, as Bouwman & MacInnes (2006) state, is regulation. Therefore, the relationship between the selected company and the government is also an important criterion. As discussed in section 1, because there are many world leading global companies operated in China, the interviewed companies should include at least one of these International companies.
- Selection of the **interviewees**. The interviewees are selected in such a way that they are experts within ICT industry in terms of their working experience and positions.

According to the criteria above, the selected interviewed companies for this case study locate in Beijing, Shanghai, Shenzhen and Zhuhai, which cover all of the three most important areas for ICT industry in China. In addition, Beijing and Shanghai are the centres for Bo Sea Gulf Area and Yangtze River Area; while Shenzhen and Zhuhai are among the important cities for ICT industry within Pearl River Area.

The selected companies cover all the five sectors for the Chinese ICT industry: EP/AP, SP/CP and operator. They either have large economic of scale or have close relationship with the Chinese government. The selected interviewed companies include both native Chinese companies and a subsidiary of a foreign company. How the individual selected companies fit the various selection criteria is shown in Table 3.

	Economic of Scale	**Close relationship with the government**	**Global company**
EP/AP	Huawei; ZTE; Nokia Beijing	Shanghai CINtel; Digi Moc	Nokia Beijing
SP/CP	Altra Information Technology Ltd.		
Operator	China Mobile; China Telecom; China Unicom	China Mobile; China Telecom; China Unicom	

Table 3. List of Interviewed Companies in Terms of Selection Criteria

Most of the interviewees from the interviewed companies have worked for ICT industry for more than 10 years. The interviewees are all above mid-level management and most of them are from top-level management.

Interview Framework

According to the purpose of this case study stated in section 1, the interviews were conducted enclosing the following four aspects:

- General information about the entire ICT industry from all five sectors' viewpoint. Within this aspect, the interviewed ICT companies within different sectors are going to outline the whole Chinese ICT industry from their point of view respectively. In this way, the Chinese ICT industry could be sketched more objectively.
- General information about each ICT sector from the interviewed companies which allocate in this sector. Here the contents are disaggregated into each of the five ICT sectors, EP/AP, SP/CP, operator. The information about how each sector within the Chinese ICT industry operates is expected to be obtained.
- The interaction among each interviewed company and the other ICT players. This aspect tries to provide information for identifying the supply chain network structure for the Chinese ICT industry.
- The future of the Chinese ICT industry from all five sectors' viewpoint. Similar to the first aspect, the future trends of the Chinese ICT industry are going to be revealed by the players from all the five sectors within ICT industry.

4. Chinese ICT Industry Network Structure

Based on the interview results, we illustrate the supply chain network structure for the ICT industry in China as in Fig.2. As mentioned in section 3, the Chinese ICT players could be sorted into five groups: **operator**, **equipment provider**, **application provider**, **service provider** and **content provider**. Besides, there are also three important ICT supply chain related members: **regulator**, **end user** and **intermediary**. Here, **MII** is the abbreviation for Ministry of Information Industry of the People's Republic of China, the governmental organization which superintends the whole information industry, including the ICT industry, in China. The functions of the different supply chain members and the relationships among them are explained in detail in this section. We use UCINET to analyze the relationships among the most important Chinese ICT companies in order to verify the supply chain network in Fig.2. At the end of this section, some words are given to discuss about the Chinese supply chain network, as well as the major difference among it and the supply chain network structures for several other countries/areas.

The ICT network structure in China is quite straightforward and different from the network structure for the western countries. The absolute control power of the Chinese government over the operating of the telecommunication industry decides that the operators have the utmost important position within the supply chain network for the ICT industry. We can read from Fig.2 that the status of the operator here equals to a focal company within its supply chain network. The ICT industry is limited within the dash-dotted rectangular. The thin line stands for the supplier-customer relationship, while the heavy line represents the regulated power relationship. The arrows of the thin lines points from the suppliers to the customers. The heavy lines go from the controllers to the under controlled supply chain members due to the existence of regulation. As mentioned in the previous section, the boundaries between application provider and equipment provider as well as between content provider and service provider are rather blur, which is also illustrated in Fig.3 with dash-dotted ovals. For instance, take a quick look at our case companies, Huawei, ZTE and Nokia Beijing are EPs as well as APs; Shanghai CINTel and Digi Moc act mainly as AP, while they outsource the equipments from EPs; Altra Information Technology Ltd. acts as both SP and CP.

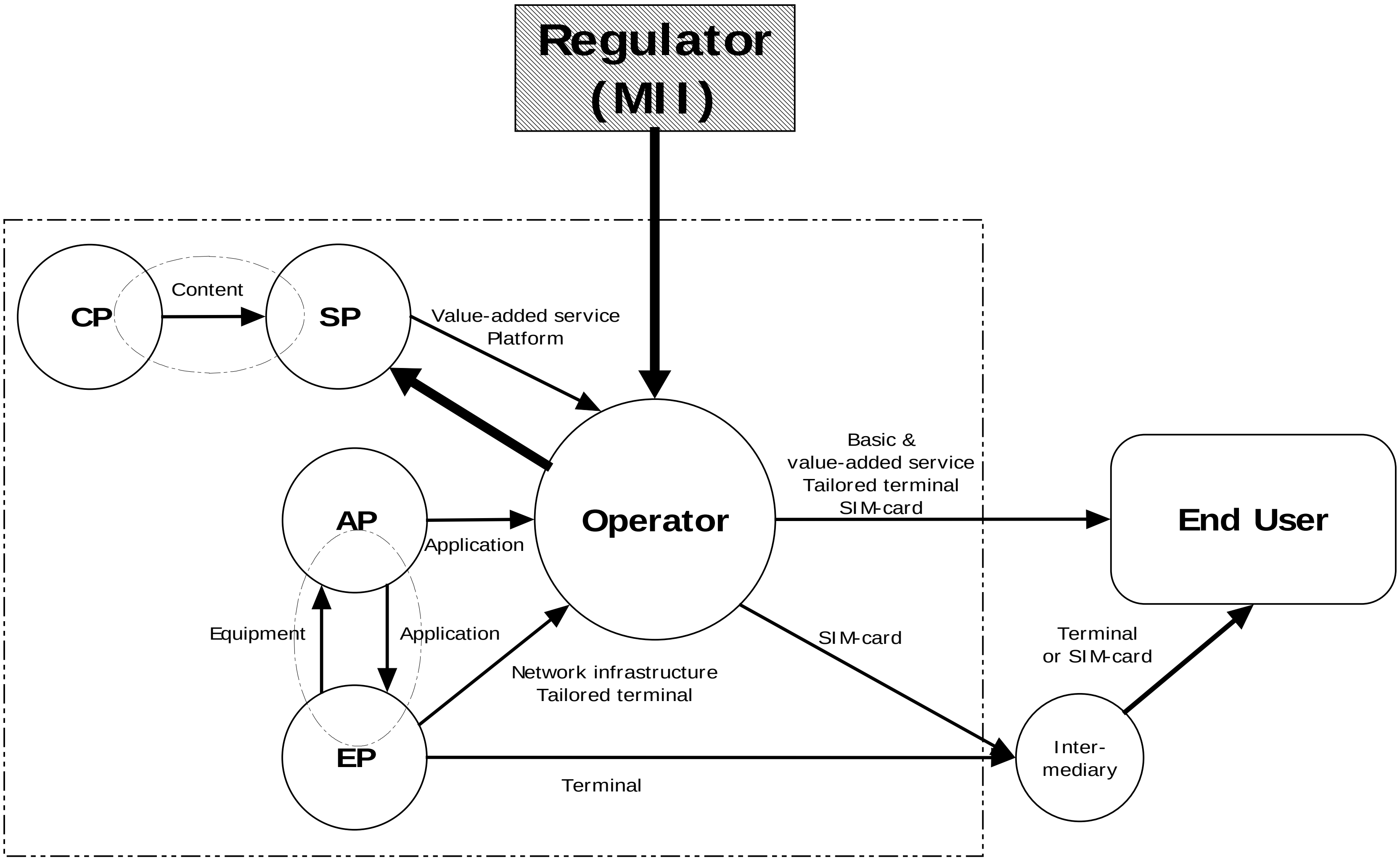

Fig.2. Supply Chain Network for the Chinese ICT Industry

Supply Chain Members within ICT Industry

Operator: As seen in Fig.2, the most important supply chain members within ICT industry is the operators, which are the focal company in the supply chain network. Operators in China are authorized by the governmental department MII to own the base network infrastructure and to operate the respective fixed-line telephone, mobile telephone and Internet related services. They face the end-users directly. They can be seen as the portal which connects the AP, EP and SP with the end users. They are also the prolocutor of MII. The operators transmit and execute the regulations that the MII has framed, while the MII consults the operators when it constitutes the regulations.

After the finishing of reorganizing the Chinese telecommunication operators in 2002, there are now six basic operators in China: China Telecom, China Mobile, China Unicom, China Netcom, China Railcom and China Satcom. Originally, there was just one operator, China Telecom, who operated fixed-line telephony as well as the earlier version of mobile handset – brick and the later on Xiaolingtong, which, in short, is a condensed mobile phone, which is available only on a certain range of areas. It costs less than normal mobile phone does in terms of the infrastructure, on the other hand, the quality of PHS is far worse than the normal mobile phone), and Internet services. Actually China Telecom was separated out from the former China Posts and Telecommunications Bureau in 1998. When the government realized the monopoly situation of the telecommunication in China, they established China Unicom in 1994 in order to break this situation. China Unicom has had all licenses for operating fixed-line telephony, mobile phone, PHS and Internet services. But the monopoly situation had not been broken as intended. In 1998, the assets and turnovers of China Unicom were just respectively 1/260 and 1/112 of China Telecom's. Therefore, in the late 1999 China Mobile was separated out from the China Telecom to concentrate on the mobile service operating. From then on, China Telecom does not own the license for mobile handset. This move intended to weaken the monopoly within telecommunication, but as a new comer to the telecommunication sector, even if the government bestowed the China Unicom a lot of preferential policy, China Unicom has been hardly competing with China Mobile and cannot pay attention to the fixed-line telephony service, which is the major area of China Telecom. In order to break the monopoly for this area, a new operator, China Netcom, came out in 2002. It has the same business sectors as China Telecom, while China telecom's major geographical business areas lies major in the South and East part of China and China Netcom operates more in the North and West. The business areas of these four largest Chinese operators are listed in Table 3.

As the name indicates, the networks of China Railcom (established in 1999) and China Satcom (established in 2001) were originally used specially for the railway communication and the national defence purpose. As the fast development of the ICT, there were spare networks left which could be used for the business purpose. Therefore China Railcom and China Satcom were established. These special conditions constrain the business scale of the two operators and therefore they are not as popular as the other four operators in China.

	Establishing Year	Market Area	
		Major Business Sector	**Geographical Area**
China Mobile	1999	Mobile network related services (GSM)	China
China Netcom	2002	Fixed network and Internet related services & PHS	North West China
China Telecom	1998	Fixed network and Internet related services & PHS	South East China
China Unicom	1994	Mobile network related services (CDMA)	China

Table 3. The Market Areas of the Major Chinese Operators

From Table 1 and Table 3, we can read that there is almost no competition among the major Chinese operators now. For the fixed-line and Internet connection services, both China Telcom and China Netcom operate within these business areas. But their business areas in terms of geographical are rather different. China Telecom has its business most in South East China, while China Netcom operates mostly within North West China. Similar situation for the operating of the mobile services, the only two mobile services operators, China Mobile and China Unicom, compete within mobile services sector, but China Mobile are almost 3 times larger than China Unicom in terms of total assets and the annual sale in 2005. Concerning the net income in 2005, China Mobile has 10.87 times than China Unicom.

The price of the telecommunication is decided definitively by MII. Before the operators push out some preferential menus or give the end users some discount, they need to get the permit from the government. In this aspect, the China Unicom gets the absolute favour from the government because of their weak competitiveness on mobile phone business compared with China Mobile. The government empowers China Unicom, for example, with lower call charges than China Mobile gets.

In addition, as the issuing of the three 3G licenses is coming soon, probably in the late 2006, another reorganizing of the operators is probably going to carry out. This change will affect the ICT industry in China. The future number of the operators directly affects the economic benefit of the equipment provider’s and the application provider’s concerning the selling of the networks or applications. For instance, if there were just one operator for 3G, the equipment providers and the application providers could just sell one set of the network infrastructure or application, which is the worst situation for them. On the other hand, this were the most cost saving situation regarding the infrastructure for the country, as they just needed pay for one instead of several sets. But if there were just one operator, the end users would be the victim. Anyway, the China Telecom is claimed having one of the three 3G licenses. Since China Telecom is the largest fixed-line operator in China, that the government issued the license of operating the PHS service, which is mobile service in nature, intents of letting China Telecom preparing for the operating of 3G related services.

Today, there are no any independent foreign operators who provide the basic services in China. Nowadays, the only role the foreign operators can play in the Chinese market is to financing through acquiring a stake in the Hong Kong-listed Chinese operators.

EP/AP: Application provider offers the software or solutions for the specific requirements the operators needed, while an equipment provider supplies the operators with the equipment needed, for example network infrastructure or tailored handsets. Although the boundary between the APs and EPs is quite hazy, the application providers and equipment providers often outsourcing from each other with their respective focal products. The two largest Chinese equipment providers are Huawei and ZTE. They act also as the application providers in China and even worldwide. Huawei and ZTE compete in the almost same business sectors as well as geographical areas. The only difference lies in the form of the ownership. Huawei is a totally private owned company, while ZTE is state owned but operated by private persons. There are also a lot of subsidiaries of the foreign equipment providers or application providers in China, as mentioned in section 1, Ericsson, Motorola, Nokia, Samsung and Siemens etc. They all have big market shares in China. Also as mentioned in Section 1, the market share of the foreign brand mobile handsets account for about 60%. Most of the application providers and equipment providers currently have been concentrating on the products that related to TD-SCDMA, which is developed by China and is among the world's three approved 3G wireless interface specifications. The other two are USA initiated CDMA 2000 and European standard WCDMA.

SP/CP: Content provider supplies the service providers with the music, video clip etc. The service provider constructs the platforms in order to, through the operators, provide the end users with the specific service, for example short message service (SMS), Interactive Voice Response (IVR), multimedia message service (MMS), etc. Besides the supplier-customer relationship between the service providers and the operators, the operator has also the control power over the service providers. The operators are empowered by the MII with the right to permit or prohibit the service providers running their business. The operators admit the service providers to offer the platforms for the services to the end users, but the operators face the end users directly and calculate the flux and take in the charges from the end users. Then the service providers receive the money from the operators.

SMS is an extremely successful value-added service in China. Yan et al. (2006) argue that, in China SMS as one of the simplest value-added services based on the GSM and CDMA standards offers the real growth in mobile data services. NEWS.CN (2006) pronounced that during the Chinese New Year 2006 (eight days), the number of the SMSs in China reached 12.6 billion! During the eight days, the average SMSs sending per person was over 30 and the earnings from SMS for the two Chinese mobile operators, China Mobile and China Unicom together, exceeded 0.13 billion EUR.

In China, several service providers also act as content providers. There are more than 1000 service providers in China and because of the immature market and the irregularly operating within this sector, the operators are planning to improve the regulations for this sector and reorganising the service providers in terms of reducing the number of SP/CPs and eliminating unqualified SP/CPs.

The self-consumption phenomenon is one of the immature manifests within the Chinese services providers. China Mobile has noticed this and has already started to punish and houseclean the service providers who have involved in the self-consumption phenomena. The self-consumption phenomenon refers to that, the service providers self buy the discounted prepaid-cards (50% off) launched by China Mobile and then consume their own companies' various value-added services. Then, according to the guide regulations of the telecommunication industry, the operator China Mobile allots the incomes that fall into the SPs' percentages according to the original agreements to the service providers who have self consumed the value-added services. The incomes are always higher than the costs that they have paid for the discounted prepaid-cards, which are referred to as red cards that contain for example the unlucky number "4" within the card numbers, compared to the white cards that do not have such suspicions and are sold with the par value.

Furthermore, the survival environment are extraordinary tough for both the small-sized EP/APs and SP/CPs. They compete very hard with the famous global firms as well as the giant Chinese companies within their business areas. The global firms have their competitive advantage on their brands, for example, Ericsson and Nokia, etc. This situation is experienced most by the small-sized EP/APs, since only less than ten licenses for the value-added services within more than 15 000 licenses were issued to the foreigh investors. Whereas the competitive advantage for the giant Chinese companies lie mostly on the price. The small EP/APs and SP/CPs have neither famous brand, nor the economic of scale and therefore they can hardly win customers from the global firms or giant Chinese companies.

Supply Chain Members outside ICT Industry

Regulator: The regulator for the Chinese ICT industry is Ministry of Information Industry of the People's Republic of China. It was established in 1998 and is the governmental department that constitutes the information industry related regulations and deals with the affairs within information industry in China. MII directly appoints or reorganizes the operators and superintends them. On the other hand, MII indirectly controls the whole ICT industry through constituting the industrial regulations, common standards and even the respective service fees. Although MII administrates the ICT related affairs, it is the governmental organization and therefore it cannot be categorized into the ICT industry bound.

It can be seen that the Chinese government has the absolute control power over the Chinese ICT industry through its directly controlling of the operators. The advantage of the highly government control is easy to plan and control the whole industry, in this way, the country assets could be saved to some extent. The disadvantage lies in that the individual ICT players cannot completely pay attention to fulfil the customers' needs, but also need to consider how to follow the government or to keep sound relations with the government. In this way, a part of the end users' benefit is sacrificed

End User: The other member who is very important for the ICT industry in China and cannot be counted in the ICT industry is end user. The end users situate at the most end of the supply network and are, therefore, the money mine for the whole ICT industry. The ultimate goal of the various supply chain members, who are within the Chinese ICT industry, to continuously develop new technology or new services is to obtain or retain the end users. Although the handsets, the different SIM-card or preferential menus and the different services are all created to fulfil the end users' needs, they actually do not have any bargain power in terms of, for example, the service fee. The end users can just accept the amount the MII has prescribed. On the other hand, the cardinal number of the end users and the potential end users in China is the advantaged precondition for the commercial profit of the Chinese ICT industry. The successful running of the value-added service SMS in China is among the examples that confirm the proposition.

One noticeable thing concerning the end user is that the inequality development of the different regions in China (South East China, the quickly developing regions, vs. North West China, the comparatively slower developing regions) and even the cultural difference in different provinces or regions lead to the different consumption behaviours of the end users. Although this phenomenon is significant, it does not relate to this paper and therefore it could be an interesting topic for the future research.

Intermediary: According to the definition for the ICT industry, the **intermediaries** cannot be ascribed to the ICT category. But the intermediaries actually play such an important role for the Chinese ICT industry that they cannot be omitted. Since in China, the selling of the handsets to the end users is primarily from the intermediaries. Although the operators order some tailored handsets in order to adapt the services or prepaid-cards they provided to the end users, much more handsets are sold to the end users through the intermediaries. Besides the wholesaling of the handsets from the EPs, some of the intermediaries wholesale the prepaid-cards from the operators as well. Furthermore the mobile handsets are usually sold separately from the SIM-cards, which is different from the major selling methods of the western countries.

Discussion

When concerning the development of the ICT industry in China, the main power comes from the EP/APs or SP/CPs together with the end users. Since the operators are empowered to occupy the best position within the supply network structure of the Chinese ICT industry, they do little for the renewing of the technology. It is always the case that the EP/APs or SP/CPs bring a new technology or service idea to the operator and persuade them to have a try without paying. The operators pay for the new technology or service only after they have got enough profit from the end users. Before finding out a new technology or a new service, the EP/APs or SP/CPs always do some kinds of market research in order to get the accurate feedback from the end users. Therefore it is the EP/APs or SP/CPs together with the end users who initiate the development of the ICT industry.

The major uncertainty of the Chinese ICT industry lies in the political transformation and the end user needs' diversification. Since the Chinese government has the absolute control power over the ICT industry, the transformation of the regulations regarding the ICT industry affects the whole industry a lot. For example, along with the releasing of the 3G license, the structure of the operators is going to be totally changed. On the other hand, the uncertainty is also accompanied with the end users. It is the end users who pay for the various products and services. In China, the large number of the end users and the inequality economic development within different geographical areas all lead to the different consumption behavior for different (groups of) end users, which enhances the uncertainty for the Chinese ICT industry.

Regarding the Chinese supply chain network structure comparing to other market regions, the main difference comes from the role of the regulators. The Chinese regulator MII has chosen continuously active (strict) role in the supply network. Supply network is operator led, but operators are appointed by MII and they involuntarily divide the country more or less to regional monopolies between each other. No free competition or foreign operators are allowed to enter the Chinese market~~s~~.

Also by MII appointment, China has developed its own 3G standard ~~(~~TD-SCDMA~~)~~. This own standard gives a better possibility for national companies to be involved in technology development already in the early stage, which at the cost of foreign network equipment providers, causes relative advantage for national firms when the networks are to be built in the future. Own standard gives the regulator a better possibility to regulate its own markets also in the future, if it chooses so. In addition in a bigger scale, this has been seen a way to reduce country's dependence on foreign technology and to run China's own interest~~s~~, therefore it has been also a highly political choice.

In Japan, the regulator in the 1990s imposed the telecom supply chain network operator-led and since then the regulator has been more passively influential organ. This lead the bloom of i-mode and through this decision, the Japanese market has been the forerunner of telecom development. However, this has given for equipment manufacturers much smaller role in the supply network, since they have been forced to follow operators' (e.g.

NTT DoCoMo) specified paths, often times at the cost of equipment manufacturers own profitability.

In Europe, the regulator in the 1990s decided the favoured technology, GSM, which was heavily lobbed by strong equipment manufacturers (especially Ericsson and Nokia). Ever since then, the regulator has had relatively passive, observer's role. This development path has given equipment manufacturers much stronger role comparing to operators than, for example, Japan.

In the USA, the regulator Federal Communications Commission (FCC) chose rather open and liberal role and gave free hands for technologies to develop favouring the technology developers and equipment manufacturers (Qualcomm). However, this caused confusion among the users of which technology to choose, because different technologies did not roam between each other (mostly by the choice of operators). This partially explained the smaller revenues of all parties in the value network and slower penetration of mobile technology in general than in Europe and Japan.

ICT Network development in China, collaboration view

We have formulated a case network in order to provide an overview of the formation of the collaborative relationships for the Chinese ICT supply chain network. The network is based on the information of strategic alliances formulated from 1998 to August 2006 of ten Chinese focal companies (Haier Group, Huawei Technologies, Lenovo, Vimiczo, Dtmobile, ZTE, China Mobile, China Telecom, China Unicom, and Hutchison Telecom), and their global and local alliance relationships. These companies are large Chinese companies from different sides of ICT industry and represent their industry sectors.

Altogether 465 valued relationships were included to the analysis and the case network consists of 239 companies (nodes). The alliance relationships with these companies illustrates the industrial ICT network, nevertheless the structure of the network is in some sense egocentric since it describes it through few focal companies. The information of the alliances was gathered from the SDC Platinum alliance database. Furthermore, the participations to the alliances were decomposed to the pairs of relationships. Finally, the UCINET software was used to formulate the structural network analysis. See for example Borgatti et al. (1992) about profound introduction to the UCINET software in network research.

We have employed the degree of *betweenness centrality* as a measure to analyze the actors (companies) structural position in the network (see e.g. Wasserman & Faust; 1994). The results of the analysis are shown in the table x. Betweenness centrality measures the extent to which a particular actor lies "between" the various other actors in the graph. The principle of the measure is to indicate actors that are between other actors in a network, thus describing the dependency of those actors. Strong betweenness centrality facilitates actors' power position or broker position in a network. It may also provide actors more control over other actors in a network. It should be noted that illustrated betweenness centrality measures are only comparable within the case network and cannot be compared with other networks. The graphical presentation of the core parts of the case ICT network is illustrated in Fig.3.

Total rank	Company Name	nBetweenness centrality	Total rank	Company Name	nBetweenness centrality
1	China Unicom *	39.809	17	Cisco Systems	1.065
2	China Telecom *	24.913	18	Millicom	0.759
3	Hutchison Telecom *	21.497	19	Hewlett-Packard	0.752
4	Ericsson	17.219	20	Telstra Corp	0.723
5	China Mobile *	14.718	21	Matra Communication	0.499
6	Haier Group *	13.925	22	Pacific Telesis International	0.499
7	Huawei Technologies *	13.925	23	British Aerospace	0.499
8	ZTE *	10.493	24	GTE	0.474
9	Nortel Networks	5.553	25	SK Telecom	0.467
10	QUALCOMM	4.485	26	Sprint	0.466
11	Motorola	4.088	27	AsiaInfo Holdings	0.433
12	Vodatel Networks Holdings	3.758	28	Korea Telecom	0.217
13	SingTel	3.549	29	Lucent Technologies	0.194
14	AT&T	1.905	30	HK Telecomm	0.128
15	Microsoft	1.881	31	StarHub Internet	0.060
16	Nokia	1.292	32	China Netcom	0.054

Table 4. Top Companies' Structural Position in China ICT Network

* Focal company

Betweenness centrality in this context can be seen as a meter for exposing the central nodes within the value network. It can be assumed that firms primarily tend to seek collaboration relationships with firms or industries, which have the most central role in the value network and who generate most value into it. As shown in the table x, telecommunication operators seem to be the most central companies (or industry) in the Chinese ICT network if firms' collaboration activeness are studied. The result is clear, since all four selected operators are in top 5 of the group, China Unicom as by far the most central single company (betweenness centrality is two times greater than the second one). As also UCINET analysis shows, operators seem to have central position in the Chinese ICT value network and thus support the findings of our study.

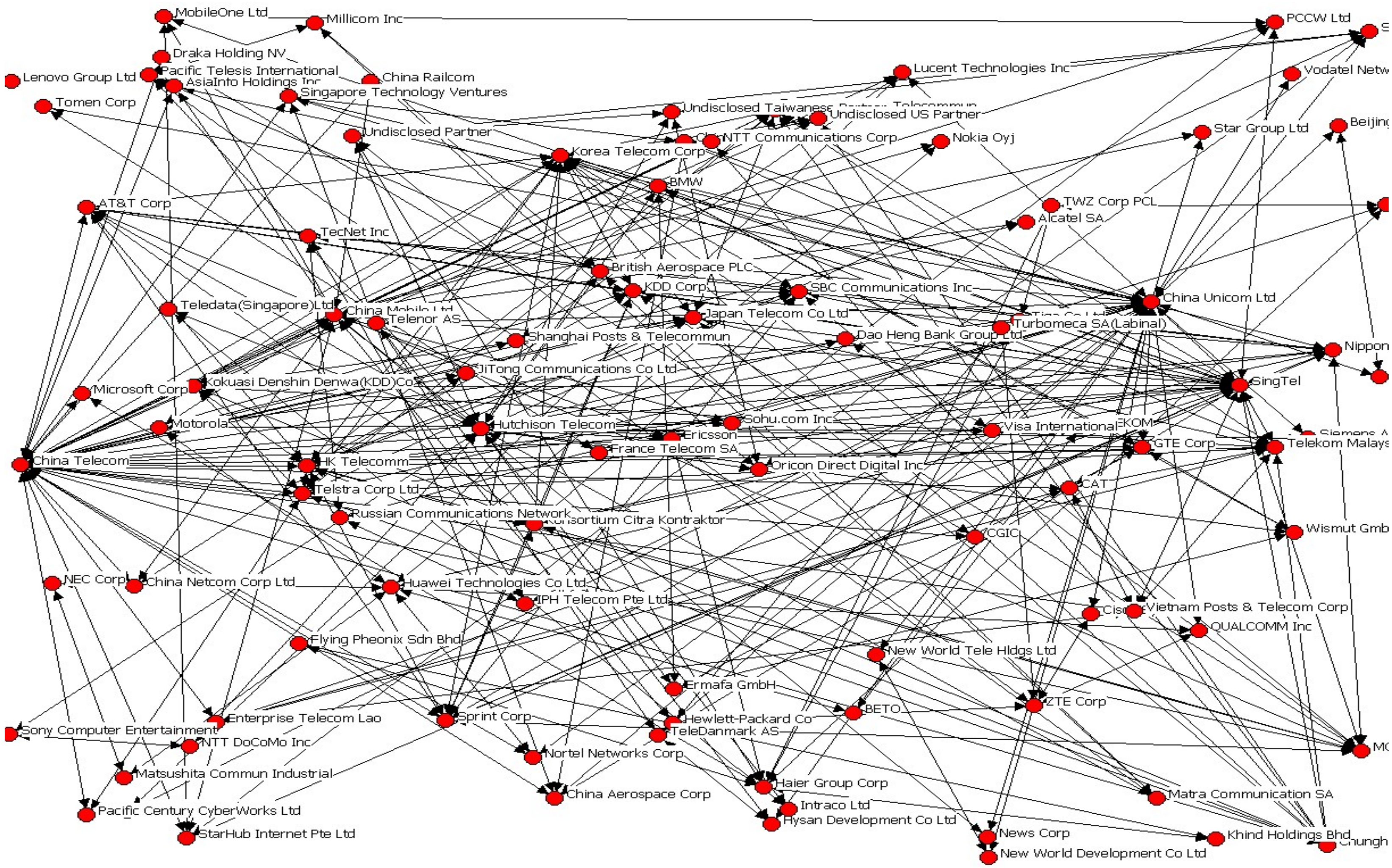

Fig.3. The Graphical Illustration of the China Alliance ICT Network

5. Chinese ICT Industry Business Processes

In this section, the Chinese ICT industry is going to be interpreted from another point of view, the supply chain business processes' perspective, according to Lambert & Cooper (2000)'s eight business processes mentioned in section 2. Also mentioned in section 2, we adopt Cooper et al. (1997)'s business processes definition, *the activities that produce a specific output of value to the customer*, which focus on the specific output that meets the end users' requirements. According to the definition for ICT industry provided by WPIIS in section 2, there does exist substantial difference between the ICT manufacturing industry and the ICT service industry. For the ICT manufacturing industry, the specific output that meets the end users' requirements is the terminal and accessories that could assist the end users to communicate with each other. For the ICT service industry, the end users are attracted by new services that help them to personalize their communication (Nokia Corporation 2004). Ring tones, streaming music, downloadable music, online and downloadable games, and the other entertainment & media channels etc. consist for the specific output within the ICT service category. Hence the supply chain business processes for ICT manufacturing industry and for ICT service industry in terms of their respective outputs need to be identified individually.

Fig.4 illustrates the supply chain business processes for the Chinese ICT manufacturing/service industry. The business processes with dash-dotted rectangular are those processes only valid for the ICT manufacturing industry. The allocating of the individual supply chain members along the key supply chain business processes is also shown in Fig.4.

Five core business processes are identified for the entire ICT industry in China: **Needs Defining**, **R&D** (Research and Development), **Manufacturing**, **Marketing** and **After-Sale Service**. Under each core business process, sub-processes are identified as well. Here the core business process **Production** is only valid for the ICT manufacturing industry. This is the essential difference between the supply chain business processes models for respectively ICT manufacturing industry and ICT service industry. Besides, there are also slightly different between the sub-processes for the ICT manufacturing industry and the for the ICT service industry.

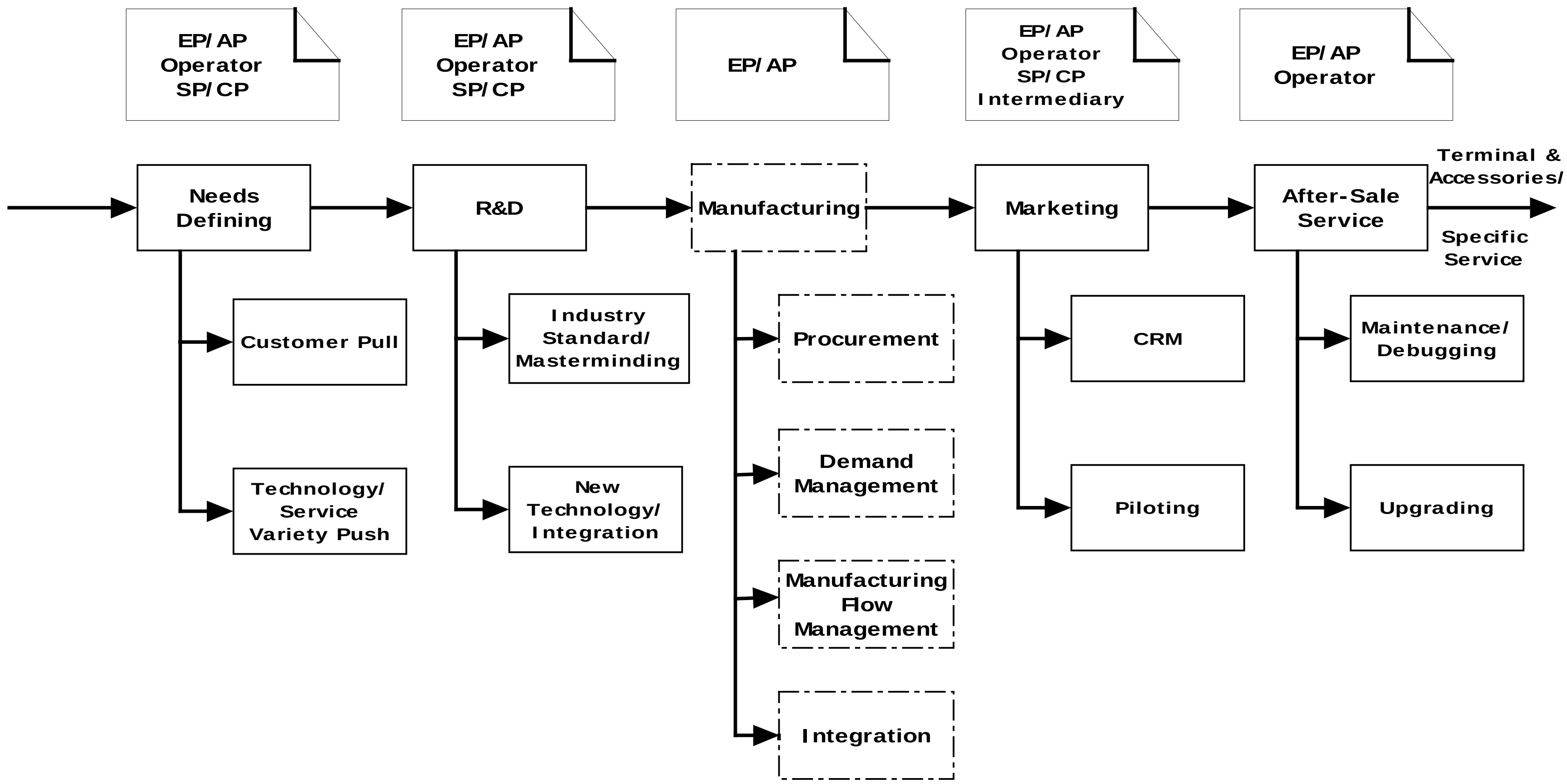

Fig.4. Supply Chain Business Processes for the Chinese ICT Manufacturing/Service Industry

Needs Defining: Needs defining is the first activity. To identify the right needs, either to collect the opinions from the end-users or to foresee the possible accepted trends, is the most important foundation for the succeeded processes. The sub-processes under Needs Defining are **Customer Pull** and **Technology/Service Variety**. The development of the technology concerning the ICT manufacturing industry is towards more mobility together with higher data compressing; while for the ICT service industry, the various players are thinking about enriching of the service variety. If some needs which could not be accepted by the end-users were identified and sent to the research and development (R&D) departments, probably an unaccepted product or service would be released. EP/AP or SP/CP together with the operator, according to the feedback from the end users and their own experiences, define the possible needs and constitute the assignment, which is the input to the next process, research and development (R&D).

R&D: Cooper et al. (1997) indicate that a critical part for a company's success is new products and R&D is also an important process for the ICT industry in China. The individual types of ICT players research and develop different prototypes or services in the process R&D. For the output terminal and accessories, the EP/APs need to research and develop the **Industry Standard** as well as the **New Technology**. Although the industry standards are not directly influenced by the end users, it is rather crucial for process R&D. The industry standards are the foundation for the new technologies. On the other hand, if the standard an EP developed is accepted by the whole ICT industry, the company is going to profit as long as the standard is accepted and used. For the specific services provided to the end users, the process R&D includes the sub-processes **Masterminding** and **Integration**. The SP/CPs together with the operators mastermind new services and contents. Then they integrate the services and the contents into services package and offer them to the end users. We can read from Fig.4 that all supply chain members within ICT industry participate in the processes Needs Defining and R&D.

Manufacturing: The process Manufacturing is rather common in all of the traditional manufacturing industries. This is also the unique business process for the ICT manufacturing industry compared with the ICT service industry and therefore the participants in this process are EPs and APs. The EPs produces the physical products terminal and accessories, while the APs provides the applications or software needed by the terminals. The sub-processes here are **Procurement**, **Demand Management**, **Manufacturing Flow Management** and **Integration**. The processes Procurement, Demand Management, Manufacturing Flow Management are detailed explained in Lambert & Cooper (2000). In the process Integration, the terminals and the applications or software are integrated together to be the finished goods to the end users.

Marketing: Lambert & Cooper (2000) indicate that marketing plays a critical role concerning the supply chain management, which is also valid for the ICT industry in China. Here, not only all the supply chain members within ICT industry attend this activity, but also the intermediary. Marketing contains three sub-processes, **CRM** (Customer Relationship Management), and **Piloting**, which are the same for both ICT manufacturing and ICT service industry. The two sub-processes correspond to the two sub-processes under the core process Needs Defining. The sub-process CRM, besides the identifying of the key customers or customer groups as in Lambert & Cooper (2000), is also to collect the opinions or feedbacks form the end users, which is one of the main bases for the core business process Needs Defining. Piloting is quite important in China. As obtained from the interviews, all of the interviewees, from all ICT sectors, emphasised the importance of using various advertising means to influencing the end users of consuming their focal products or service. Therefore, Piloting is listed here as one of the sub-processes under Marketing. This is the corresponding sub-process to Technology/Service Variety Push under the core process Needs Defining.

After-Sale Service: This process includes two sub-processes, **Maintenance/Debugging** and **Upgrading** for ICT manufacturing/service industry. The EP/APs are responsible for the maintenance and upgrading the terminals and accessories; while the operators debug and upgrade the various services provided to the end users.

6. Future of ICT Industry in China

Next some important issues that have come up during the interviews that will have an impact on Chinese ICT industry and are going to happen in the near future. According to Nokia (2004), “Regarding the development trend of the technology, the direction is toward more mobility together as higher data compressing. As voice matures, the future of operator business growth and profitability lies in multimedia services and mobility.” This applies also in Chinese context. However, the mobile penetration level in China is still rather low (around 35% by the end of the year 2006) compared to, for example, EU that is closing to 100 % already. Therefore it can be assumed that this trend is somewhat lagging on Chinese markets and the main growth driver will still be voice services and “traditional” penetration growth, at least for next few years.

Related to 3G network licenses, there are couple of questions that are connected with this license release. The reorganization of the operators is planned to be carried out together with the release of the 3G licenses. The first question is technological, whether China grants operating licenses for two or three 3G technologies (TD-SCDMA, WCDMA, and CDMA2000). The main issue is whether or not CDMA2000 technology will receive a license together with two other technologies. Another question linked to this is timing. The delay on unfinished TD-SCDMA technology development may delay 3G license granting in general. However, this technology and its full development is seen as such high importance within China that the delay in the license granting is seen justifiable. The other main issue is that 3G license granting will reorganize also Chinese operator landscape, which current operators will be granted with the license, where they will operate geographically in the future, and whether new operators are formed in addition to the current ones. Also the question of opening the markets to foreign operators will be put out herewith. Finally, this reorganization will affect also to SP/CPs depending on the decisions made on other levels.

Partly these decisions have an effect, or are affected by, on more general level on Chinese trade politics. For instance, WTO's opinion on and free trade in general may play a role in the question of whether and when foreign operators are accepted to Chinese markets. Similarly, their attitude on IPR issues and pressure power to Chinese government can cause changes on general level. These changes would have a notable effect on SP/CP and consequently also operators' role. Choices made in these different political stages may affect even fast to the ICT network environment and the power structure of it.

7. Conclusion

In this paper, we examine the Chinese ICT industry in terms of its supply chain network structure and the supply chain business processes. With the supply chain network structure, we identified the relationship among the individual supply chain members. By using UCINET, we have verified the major findings from the supply chain network that the Chinese operators are the focal companies of the whole Chinese ICT industry. From the supply chain business processes, the business processes clarifies the transferring of an ICT-related product or service from the business idea to product that can be offered to the end users.

8. Future Study

The supply chain business processes identified in section 5 is the special case for the Chinese ICT industry and is the first trial for the ICT industry especially for the service sector. The verifying of the business processes could be further studied in the future.

Our intention of identifying the business processes is to configure a common model which assists the practitioners for the transferring of a new business idea to the merchandise. In the future, the business processes for the ICT industry in other countries could be also studied. After integrating them with the verified business processes within the Chinese context, a general business process model for the ICT industry could be obtained. Eventually, the value adding of each business process could be identified, which could help us to identify the key business processes with more value adding and thus put more effort on these key business processes.

The Chinese ICT industry has its own characteristic, which are described in the previous sections. It is an interesting topic to discover the differences between China and the western countries, for instance, Finland and Sweden. For the ICT manufacturing industry, the major difference between China and the western countries, for instance Finland, is that the western countries doing most for R&D, while moving most of their manufacturing to China or East European countries, while the Chinese ICT giants, for example Huawei and ZTE, extend their R&D worldwide besides their plenty R&D centres in China. For the ICT service industry, compared to China, the competition in the western countries is rather unrestricted, which is discussed in section 4. All of these are worth being further examined.

Collaboration analysis shown in section 4 (UCINET) was made for the selected group's of firms within the industry. This group (however extensive) is naturally just a sample of the whole industry. The analysis could be widened to cover either all ICT firms' alliances within China (national and foreign), or to all Chinese ICT firms' alliances (inside/outside China), or both. This would give a full picture of collaboration and its development in the whole Chinese ICT industry.

Because of the limitation described in section 2, this case study could not be conducted to more detail in terms of the categorization of the individual supply chain members. The supply chain network for the Chinese ICT industry could be disaggregated to much detailed extent after doing more interviews. For instance, the equipment provider could be further divided into: terminal provider, network provider, component provider etc.

Besides, as mentioned in section 4, the end users in different regions in terms of the inequality economic development and different culture and could be further studied in order to discover the different consumption behaviours. This information could be crucial for the ICT related practitioners who want to enter the Chinese market.

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Appendix ICT Value Network (Adapted from Hallikas et al. 2005)

Building Blocks Suppliers

- **Electronic components:** *Intel, Atmel*
- **Operating systems:** *Microsoft, Nokia*
- **Mechanical components:** *Zeiss, Perlos*
- **Application software:** *Microsoft, Borland*
- **Contract manufacturers:** *Sanmina, Flextronics*

Network & Service System Technology Providers

- **Mobile device manufacturers:** *Nokia, Sony-Ericsson, Samsung*
- **Wireless device manufacturers:** *HP, Dell*
- System software providers: *SAP, Oracle, Remedy*
- Network system providers: *Ericsson, Nokia, Cisco*
- **Service delivery platform providers:** *HP, IBM, Nokia, Ericsson*
- **Network infrastructure hardware providers:** *Cisco, Nokia, Ericsson*
- **Network infrastructure software providers:** *Microsoft, IBM*

Communication Infrastructure Service Operators

- **Mobile operators:** *TS, Vodafone*
- **Fixed network operators:** *British Telecom*
- **Broadband network Owners:** *AT&T*
- **TV broadcasters:** *NBC, Canal*

Digital Substance Providers

- **Content**: *AOL, MTV3, NBC, Universities, Gartner*
- **Apps & Services**: AOL, MSN, *Amazon, Google, eBay, mySAP*
- **Virtual network operators**: *Virgin mobile, TDC Song*
- **VOIP operators:** *Skype, MSN, GMail*

Integration, Installation & Maintenance

- **Service integration:** *TietoEnator, Ericsson*
- **Installation & Maintenance** *All technology providers*

Channel Intermediaries

- Connection reseller: *Päämies*
- Device distributor: *Päämies*
- Connection assembly: *Päämies*
- **Service integration:** *TietoEnator, Ericsson*

Capacity Coordination Contracts for Fashion Goods Supply Chain

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Abstract: The uncertainty of market demand, capital-intensive investment, and rapid technology innovation in the fashion industries makes the supply chain partners very difficult to coordinate their capacity decisions. Lacking of coordination between partners has a negative impact on the supply chain's channel efficiency. The long-term contract, which is used widely in practice in many fashion industries, does not lead to supply chain coordination. We have proposed how manufacturer can use cost-revenue and coordination-overflow sharing contracts to enhance the supplier decision capacity in repeated transactions in a two-stage fashion goods supply chain. These contracts allow channel efficiency to be achieved as well as they could improve the profits of all the partners and maximize the total profit of the supply chain.

Keywords: supply chain; channel coordination; incentive; capacity; fashion goods

1. Introduction

Globalization makes it possible for firms to operate in a wide and complex international market by matching agility and efficiency. This can be achieved either by splitting geographically the production capacity or by working together in a supply

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chain involving several independent entities (Wiendahl and Lutz, 2000). Firms need to be able to design, organize and manage distributed production networks where the actions of any entity affect the behavior and the available alternatives of any others in the network [2].

On the one hand, the fashion goods supply chains (semiconductor, personal computers, apparels, toys) are confronted with short product life cycle and demand uncertainty. This is not only the case for the fashion industry, but if we take for example an integrated circuit (IC) product that faces high demands today may be quickly outdated in a few months with the introduction of a next-generation chip. The demand volatility of IC could be as high as 80% in a quarter in the telecommunication industry (Jin and Wu, 2006). Also, earlier studies reported that the return rates of 30 – 50 % (Eppen and Iyer, 1997) leading to huge increase in markdowns (Fisher et al., 1994) in apparel industry. If manufacturers do not respond quickly and adequately to demand fluctuations in the market place, they either accumulate excess inventory or spend excessively to source capacity in the last minute. Often they also face risks of shortages and lost sales. For instance, to fulfill the increasing demand of IC which was boosted by the computer network foaming in 2001, many IC manufacturers expanded their capacities greatly. However, the demand declined to the bottom since the break of network economy foam in 2001. As a result, the supply chain suffers great loss for the cause of demand uncertainty.

On the other hand, the capacity expansion of fashion industries is capital-intensive, long lead-time for capacity construction, and rapid technology advancement. For example, the capital cost for a semiconductor manufacturing Fab. is about 500 millions to 2 billions. The equipment procurement lead-time is usually as long as 6–12 months. The life cycle of semiconductor facilities is about 5 years. New evolving manufacturing processes create high variability in yields, and consequently uncertainty in the manufacturing throughput, which in turn leads to uncertainty in capacity. Therefore, capacity management is an important issue in the fashion industries. If a manufacturer cannot respond quickly to the demand fluctuation, it accumulates excessive inventory or spend excessive money for source capacity. Otherwise, it may face risks of shortages and lost their sales.

To avoid the demand and capacity uncertainty risk, many manufacturers are conservative to expand their capacities, limiting their downside risk at the expense of supplier's potentials (Erkoc and Wu, 2002). Many original equipment manufacturers (OEM) usually reserve capacities without any cost from the suppliers based on demand forecast. Benefiting from large supplier capacity commitments while not directly bearing the costs, manufacturers are inclined to initially over-forecast before eventually purchasing a lower quantity from their suppliers. As a result, it cascades the "bullwhip effect", which further exacerbates the uncertainty in the supply chain. Therefore, the individual rational suppliers are inclined to keep their capacity relatively low to avoid creating idle capacity. Knowing what is at stake, manufacturers begin to seek opportunities to share the capacity risk with the suppliers. In practice, some manufacturers are involved in the building of upstream capacities, and some manufacturers commonly forge long-term contract with their suppliers. They share the demand information by VMI, CFPR, QR, etc. to reduce the impact of demand uncertainty. All these efforts not only reduce the supplier's capacity expansion risks, but also ensure supply for manufacturers.

This paper addresses the issue of coordination capacity contracts for fashion goods supply chain. Our investigation focuses on the long-term contract, which is widely used in practice. From our analysis, we find that although the long-term contract can improve the channel efficiency, it cannot achieve channel coordination. To overcome the weakness, we proposed new schemas to mitigate the inefficiency.

The remainder of the paper is organized as follows. In section 2, we review the related literatures on supply chain capacity coordination. This is followed by section 3 that investigates the inefficiency of the long-term contract. Then we make the analysis for the proposed two capacity coordination contracts that lead to the supply chain coordination efficiency could be enhanced. In section 4, a numerical example is presented and the sensitivity of the schemas is discussed. Finally, section 5 discuss the managerial insights of the contracts and draw the conclusions.

2. Literature review

Most of the supply chain is decentralized, where there is the problem of “double marginalization”, which means that coordination failure arises in a serial supply chain because there are two margins and neither firm considers the entire supply chain’s margin when making a decision (Spengler, 1950). It is suggested that supply chain contracts can be used to overcome the effects of double marginalization. A supply chain contract provides incentives to all firms in a supply chain so that the decentralized and uncoordinated supply chain behaves nearly or exactly the same as an integrated one (Wang, 2002; Cachon, 2002). Usually a supply chain contract is designed to share risk and profit among the partners, thereby inducing them to coordinate their decisions. Supply chain contracts such as wholesale, revenues sharing, options, buyback, quantity flexibility, backup, price protection, and sales rebate have been studied extensively in the literature (e.g., Eppen and Iyer 1997; Tsay and Lovejoy 1999; Lee et al., 2000; Whang, 1995; Cachon, 1998; Lariviere,1998; Tsay et al., 1998). Cachon (2002) has done excellent reviews.

The supply chain contracting literature examined the impact of court-enforceable contracts on capacity decisions. The seminal works by Klein et al. (1978) and Williamson (1979) proposed that if the values of supplier and the buyer's assets depend on their collaboration, they need to forge complete, contingent contracts to align their capacity investments incentives. Hart and Moore (1990), and Bolton and Whinston (1993) proposed the conditions under which various forms of supply chain structure (e.g. integration, decentralized) provide optimal incentives for capacity investment. If both price and capacity are contractible, the buyer can maximize the total supply chain profit and appropriate it entirely by properly specifying the terms of the contract (Cachon and Lariviere, 2001; Taylor and Plambeck, 2006). When capacity is not contractible, firms may employ contracts which only specify the unit price (Lariviere and Porteus, 2001).

Capacity reservation contract is a common practice in several fashion goods supply chain, which permits buyers to reserve capacity from the supplier in advance (Tsay, 1999). It helps to mitigate the "bull-whip effect" characteristic of several supply chains (Lee et al., 1997). A good contractual agreement could lower the supplier and the buyer's cost due to better capacity planning (Serel et al., 2001). Silver and Jain (1994) and Jain and Silver (1995) proposed a capacity reservation contract where the buyer pays a nonrefundable premium to the supplier to guarantee the supply in a stochastic demand. Cachon and Lariviere (2001) and Tomlin (2003) investigated the court-forced and voluntary compliance reservation contracts and proposed that a supply chain can be coordinated by court-forced reservation contract. Jin and Wu (2001) proposed the "take-or-pay" contract for capacity coordination in high-tech manufacturing. Where a reservation fee paid by the supplier will be deducted at the time the customer places an order. The buyer pays penalty for unused capacity after the realization of the demand. This mechanism will enable the supplier to plan capacity expansion. Jain and Silver (1995) considered capacity reservation decisions and develop an algorithm to determine the optimal level of capacity reservation from the buyer's perspective without considering the interaction between the manufacturer and the customer. Erkoc and Wu (2004) proposed a cost sharing and a partially deductible capacity reservation contract to achieve capacity coordination. Jin and Wu (2006) proposed a deductible reservation contract for capacity in high-tech supply chain. Kim (2003) proposed a dynamic outsourcing schema which can reduce the supply cost to coordinate manufacturers with different capabilities. Deshpande and Schwarz (2002) studied the capacity allocation between multiple manufacturers and a supplier with asymmetric information. They proposed an auction mechanism where retailers submit purchasing cost bids for supplier capacity. This mechanism can increase both partners' profit significantly.

In the vast literature about supply chain coordination, there is relatively less attention paid to the long-term relationship which is widely used in practice for capacity coordination. Debo (1999) shows that when the supplier's pricing game is infinitely repeated (and demand has a uniform distribution), all the partners' expected profit could be increased in each period. Baker et al. (2001, 2002) studied the repeated procurement schema and proposed that outsourcing is optimal for the supply chain where the capacity is costly and the market price is little variable. Taylor and Plambeck (2006) proposed the conditions to achieve capacity coordination in a two-stage innovative product supply chain. The buyer and the supplier forge informal agreements that will be sustained by repeated interaction. Frascatore and Mahmoodi (2003) proposed a long-term and penalty contract to coordinate the capacity decision in an integrated two-stage supply chain.

In the previous works, little has been studied on the effect of decentralization in a stochastic decision in a decentralized fashion supply chain. As we demonstrate in this paper, the fact that the volatile demand, the capital-intensive and the rapid technology advancement of the capacity creates challenging issues in fashion goods supply chains.

3. Model Formulation

3.1 Assumptions

We consider a two-stage supply chain involving a manufacturer and a supplier. Both of them are risk neutral. The demand of the final product is stochastic. The manufacturer performs no production and carries no inventory. They buy from the supplier and satisfy customer demands at wholesale price w in the make-to-order fashion. They make the components into the final product with a unit manufacturing cost c_m to satisfy customer demands. We assume that the wholesale price is exogenous since it is a common practice in the fashion industries that the manufacturer always negotiates the wholesale price before he makes order with the supplier. For each unit sold, the manufacturer receives exogenously specified revenue of p: ($p>w+c_m$). The supplier must invest in building his capacity before the demand uncertainties are resolved. The supplier and manufacturer collaborate with a demand information-sharing schema (e.g. VMI, CPFR), which ensures that the final demand is known before the supplier fills the manufacturer's order.

The final demand for the manufacturer is a random variable x. The probability density and cumulative distribution of x follow functions $f(x)$ and $F(x)$ respectively. Where $f(x)$ is strictly positive and continuous, and $F(x)$ is strictly increasing and continuously differentiable $(0<F(x)<1)$. There are two stages in the game. In the first stage, the supplier and the manufacturer requires the supplier compulsorily to fulfill the manufacturer's demand (final demand). The supplier then chooses capacity *k* before the final demand is realized. For the second stage, at the beginning the final demand is made known to all the members via the demand information sharing system. The manufacturer then places an order which is equal to the final demand. The supplier's delivery to the manufacturer is less or equal to *k*.

The supplier creates capacity at a cost c_I of per unit at the beginning. c_I includes the capacity investment cost and the supplier's opportunity cost when it devoting a unit of capacity to the manufacturer. A unit of capacity can be converted into one component per period at a production cost of c_P. The supplier incurs the production costs only when filling the manufacturer's order. The sum of the costs $c_I + c_p$ is less than the wholesale price *w*.

3.2 Double Marginalization

At first, we consider a centralized supply chain where the partners make integrated capacity decisions to optimize channel efficiency. In this case, the optimal capacity is defined by the classical newsvendor solution. The expected sales volume in this period is $S(k)$:

$$S(k) = \int_0^k xf(x)dx + \int_k^\infty kf(x)dx = k - \int_0^k F(x)dx \qquad (1)$$

For any given capacity *k*, the integrated channel profit is:

$$\Pi_C^I(k) = (p - c_p - c_m)S(k) - c_I k \qquad (2)$$

And the channel optimal capacity is:

$$k_C^* = F^{-1}(1 - \frac{c_I}{p - c_p - c_m}) \tag{3}$$

Then we consider a decentralized supply chain without any coordination of the members. For any given capacity *k*, the supplier's profit is:

$$\Pi_S^D(k) = (w - c_p)S(k) - c_I k \tag{4}$$

Therefore, the individual rational supplier chooses the optimal capacity k_S^* which maximized his profit as:

$$k_S^* = F^{-1}(1 - \frac{c_I}{w - c_p}) \tag{5}$$

When the supplier chooses k_S^*, the manufacturer's profit is:

$$\Pi_M^D(k_S^*) = (p - w - c_m)S(k_S^*) \tag{6}$$

Since $w<p-c_m$, it is straightforward to verify that $k_S^* < k_C^*$. It implies that there is double marginalization. Where the supplier chooses a capacity lower than the channel optimal capacity since the decentralized supply chain has not any coordination. As a result, the channel efficiency (EC) is less than 1.

$$EC = \frac{\Pi_M(k_S^*) + \Pi_S^*(k_S^*)}{\Pi_C^I(k_C^*)} < 1 \tag{7}$$

Since $F(x)$ is an increasing function, it is easy to verify that the higher the c_I, the less the k_S^*, and the more the difference of k_C^* and k_S^*. Therefore, it is more difficult to achieve system optimal capacity in the fashion goods supply chain where the capacity is capital intensive.

3.3 Long-term Coordination Contract

We suppose a manufacturer and a supplier forge a long-term coordination contract such that they repeat their transaction in the *n* periods, since it is a common practice in fashion industry. The depreciation rate of capacity in each period is $\alpha \in (0,1)$. The salvage value for capacity is assumed to be zero. Since there is a deprecation of the capacity as αk units in each period, the supplier has to supplement αk units at the end of each period. As a result, the supplier creates $k+(n-1)\alpha k$ units totally in the n periods. The total sales in the *n* periods are:

$$S_n(k) = n[k - \int_0^k F(x)dx] \tag{8}$$

And the total profit of the centralized supply chain in the *n* periods is:

$$\Pi_{Cn}(k) = (p - c_p - c_m)Sn(k) - c_I[k + (n-1)\alpha k] \tag{9}$$

$$\text{Let} \qquad \Delta = \frac{1+(n-1)\alpha}{n}. \tag{10}$$

It is easy to draw the channel optimal capacity k_{Cn}^* that maximizes the profit of the supply chain.

$$k_{Cn}^* = F^{-1}(1 - \frac{c_I \Delta}{p - c_p - c_m}) \tag{11}$$

The centralized model acts primarily as a benchmark against which the more common decentralized supply chain design can be compared. With the decentralized control, the supplier's total profit in the *n* periods with any capacity *k* is:

$$\Pi_{Sn}(k) = (w - c_p)S_n(k) - c_I kn\Delta \tag{12}$$

The individual rational supplier chooses the local optimal capacity:

$$k_{Sn}^* = F^{-1}(1 - \frac{c_I \Delta}{w - c_p}) . \quad (13)$$

It is easy to verify that $k_{Sn}^* > k_S^*$ and $k_{Cn}^* > k_{Sn}^*$, which implies that the long-term coordination contract stimulates the supplier to build more capacity than k_S^*. But the supplier's optimal capacity is still less than the channel coordination capacity. In other words, the channel efficiency is less than 1.

3.4 Cost-Revenue Sharing Contract

The next two our alternative methods has based its analysis on the two capacity coordination contracts, i.e. The cost-revenue sharing contract and the coordination-overflow sharing contract which can achieve channel efficiency. In this part, we state the first contract which is based on theorem 1.

Theorem 1: The long-term contract with cost-revenue sharing schema (β, γ) stimulates the supplier building the channel efficiency capacity. Where the manufacturer shares a fraction (β) of the supplier's capacity cost and gets a fraction (γ) of the supplier's revenue. The mathematical representations for the parameters β and γ are:

$$Max(\frac{p - w - c_m}{p - c_p - c_m}, \frac{\Pi_{Mn}(k_{Sn}^*)}{\Pi_{Cn}^*(k_{Cn}^*)}) < \beta < 1 - \frac{\Pi_{Sn}^*(k_{Sn}^*)}{\Pi_{Cn}^*(k_{Cn}^*)} \quad (14)$$

$$\gamma = \frac{\beta(p - c_p - c_m) - (p - w - c_m)}{w - c_p} \quad (15)$$

Proof: With a CRS (cost-revenue sharing) contract, the manufacturer shares the capacity cost with the supplier, and shares the supplier's revenue. The CRS contract defined here is an extension of the cost sharing contract of Erkoc and Wu (2004). We employ an additional modification where the supplier and the manufacturer repeat their transactions in *n* periods with a demand information-sharing schema. Suppose the manufacturer pays a fraction β of the capacity cost with the supplier in the *n* periods, where β would be $0<\beta<1$. And it gets a fraction γ of the supplier's revenue, where $0<\gamma<1$. With this arrangement, the supplier's total profit in the *n* periods is:

$$\Pi_{Sn}^{CRS}(k)=(1-\gamma)(w-c_p)S_n(k)-c_I(1-\beta)[k+(n-1)\alpha k] \tag{16}$$

The manufacturer's total profit in the *n* periods is:

$$\Pi_{Mn}^{CRS}(k)=[(p-w-c_m)+\gamma(w-c_p)]S_n(k)-c_I\beta[k+(n-1)\alpha k] \tag{17}$$

The first order of the manufacturer's profit function with *k* is:

$$\frac{d\Pi_{Mn}^{CRS}(k)}{dk}=n[(p-w-c_m)+\gamma(w-c_p)][1-F(k)]-c_I\beta[1+(n-1)\alpha] \tag{18}$$

And the second derivative of the manufacturer's profit function with *k* is $-n[(p-w-c_m)+\gamma(w-c_p)]f(k)<0$. Therefore, we can draw the manufacturer's optimal order by $\frac{d\Pi_{Mn}^{CRS}}{dk}=0$, which is simplified to the condition that:

$$k_{Mn}^{CRS*}=F^{-1}\left(1-\frac{c_I\beta\Delta}{(p-w-c_m)+\gamma(w-c_p)}\right) \tag{19}$$

Let $k_{Mn}^{CRS*}=k_{Cn}^{*}$, we draw the condition that can maximize the manufacturer's profit and the total profit of the supply chain.

$$\gamma(w-c_p)=\beta(p-c_p-c_m)-(p-w-c_m) \tag{20}$$

Since $\gamma>0$, therefore we get

$$\beta > \frac{p - w - c_m}{p - c_p - c_m} \tag{21}$$

And the manufacturer gets a profit as:

$$\Pi_{Mn}^{CRS}(k) = \beta \Pi_{Cn}^{CRS}(k) \tag{22}$$

Therefore, the supplier gets the profit as $\Pi_{Sn}^{CRS}(k) = (1-\beta)\Pi_{Cn}^{CRS}(k)$. To maximize its profit, the individual rational supplier chooses its capacity as $k_{Sn}^* = k_{Cn}^*$. And we get:

$$\gamma = \frac{\beta(p - c_p - c_m) - (p - w - c_m)}{w - c_p} \tag{23}$$

To ensure that the manufacturer and the supplier are all willing to take part in the CRS schema, we need $\Pi_{Mn}^{CRS*}(k_{Mn}^*) > \Pi_{Mn}(k_{Sn}^*)$, and $\Pi_{Sn}^{CRS}(k_{Cn}^*) > \Pi_{Sn}(k_{Sn}^*)$. Then we take:

$$Max(\frac{p - w - c_m}{p - c_p - c_m}, \frac{\Pi_{Mn}(k_{Sn}^*)}{\Pi_{Cn}^*(k_{Cn}^*)}) < \beta < 1 - \frac{\Pi_{Sn}^*(k_{Sn}^*)}{\Pi_{Cn}^*(k_{Cn}^*)} \tag{24}$$

Therefore, the total profit of the supply chain is maximized, and all the firms' profits are improved. As $(0 < \gamma < 1)$ & $(0 < \gamma < 1)$ a result, it is easy to draw that the channel efficiency is $EC = 1$. With CRS contract, β is dependent on the bargaining power of the supplier and the manufacturer.

3.5 Coordination-Overflow Sharing Contract (COS)

The second contract basis its analysis on theorem 2 which is stated as the follows:

Theorem 2: The coordination-overflow sharing contract (δ_p, ϕ) **:** ϕ $(0 \le \phi < 1)$ **stimulate the supplier building the channel efficiency capacity, where the**

manufacturer pays δ_p to the supplier.

$$\delta_p = n\Delta c_I (k_{Cn}^* - k_{Sn}^*) - n(w - c_p)[(k_{Cn}^* - k_{Sn}^*) - \int_{k_{Sn}^*}^{k_{Cn}^*} F(x)dx] + \phi(\Pi_{Cn}^*(k_{Cn}^*) - \Pi_{Cn}(k_{Sn}^*)) \quad (25)$$

Proof: In the fashion industries, the OEM manufacturers are always the leader of the supply chain and the supplier has to fulfill any order from the manufacturer. Suppose the manufacturer asks the supplier to create a capacity which is different to the supplier's optimal capacity k $(k \neq k_{Sn}^*)$. If the supplier follows the manufacturer's requirement and builds its capacity to *k*, the manufacturer will get more profit as:

$$\Pi_{Mn}(k) - \Pi_{Mn}(k_{Sn}^*) = n(p - w)[(k - k_{Sn}^*) - \int_{k_{Sn}^*}^{k} F(x)dx] > 0 \quad (26)$$

And the supplier's total profit in the *n* periods is:

$$\Pi_{Sn}(k) = (w - c_p)S_n(k) - n\Delta c_I k \quad (27)$$

And he suffers a profit loss as:

$$S_{Loss} = \Pi_{Sn}^*(k_{Sn}^*) - \Pi_{Sn}(k) = n(w - c_p)[\int_{k_{Sn}^*}^{k} F(x)dx - (k - k_{Sn}^*)] + n\Delta c_I (k - k_{Sn}^*) > 0 \quad (28)$$

Therefore, the individual rational supplier will not build its capacity to *k*. Let us suppose the manufacturer promise to compensate the supplier's loss to stimulate it to expand its capacity, then the changes of his profit is:

$$CO = n(p - c_p - c_m)[(k - k_{Sn}^*) - \int_{k_{Sn}^*}^{k} F(x)dx] - n\Delta c_I (k - k_{Sn}^*) = \Pi_{Cn}^*(k) - \Pi_{Cn}(k_{Sn}^*) \geq 0 \quad (29)$$

It implies that there emerges the "coordination-overflow profit (CO)" for the manufacturer after his compensation of the supplier's profit loss. After the compensation, the supplier's profit is no less than his local optimal profit. Furthermore, suppose the manufacturer shares a fraction ϕ $(0<\phi<1)$ of CO with the supplier to stimulate the supplier to choose channel optimal capacity. After the CO sharing, the supplier's profit is:

$$\Pi_{Sn}^{*}(k_{Sn}^{*})+\phi(\Pi_{Cn}^{*}(k)-\Pi_{Cn}(k_{Sn}^{*})) \quad (30)$$

Therefore, when the total profit of the supply chain is maximized, the supplier's profit is maximized. The individual rational supplier will choose the channel optimal capacity $k = k_{Cn}^{*}$. In summary, the manufacturer pays δ_p to the supplier.

$$\delta_p = n\Delta c_I(k_{Cn}^{*}-k_{Sn}^{*}) - n(w-c_p)[(k_{Cn}^{*}-k_{Sn}^{*}) - \int_{k_{Sn}^{*}}^{k_{Cn}^{*}} F(x)dx] + \phi(\Pi_{Cn}^{*}(k_{Cn}^{*})-\Pi_{Cn}(k_{Sn}^{*})) \quad (31)$$

Therefore, the supply chain achieves channel efficiency where $EC = 1$. With this arrangement, all the members' profits are improved and the total profit of the supply chain is maximized. Finally the result shows that the COS contract is a Pareto optimal solution for both supplier and manufacturer.

4. Numerical Example and Sensitivity Analysis

4.1 Numerical Example

The demands are assumed to follow U [a, b], with the mean as E(U)=10, and p=7, w=4, c_I=1.5, c_p=1.0, c_m=1.0, and $\alpha = 0.2$. Table 1 shows the summary of the coordination results of the supply chain with the contracts.

(1) The first row shows that without any coordination, the supplier's optimal capacity is $k_S^{*} = 10$, which is smaller than the channel optimal capacity $k_C^{*} = 12$. The profit of the supplier and the manufacturer in each period is $\Pi_S^D(k_S^{*}) = 11.25$, and $\Pi_M^D(k_S^{*}) = 17.5$. Therefore, the efficiency of the supply chain will be: $EC = \dfrac{\Pi_S^D(k_S^{*}) + \Pi_M^D(k_S^{*})}{\Pi_C^I(k_C^{*})} = 96.64\%$.

(2) The second row shows that as the manufacturer and the supplier forge a 5 years long-term coordination contract, the supplier expands capacity to $k_{Sn}^{*} = 13.2$, which

is still smaller than $k_{Cn}^{*}=13.92$. Their profits are $\Pi_{Sn}^{*}(k_{Sn}^{*})=111.93$, $\Pi_{Mn}(k_{Sn}^{*})=98.38$. As a result, the efficiency of the supply chain is improved to: $EC=\dfrac{\Pi_{Sn}^{*}(k_{Sn}^{*})+\Pi_{Mn}(k_{Sn}^{*})}{\Pi_{Cn}^{I}(k_{Cn}^{*})}=99.69\%$.

(3) The third rows shows that as the manufacturer and the supplier collaborate with a CRS contract, we yield $[0.4, 0.4663]<\beta<0.4694$. Let $\beta=0.468$, and we derive $\gamma=0.1133$. With the CRS contract, the supplier's optimal capacity k_{Sn}^{*} is the same as the channel optimal capacity $k_{Cn}^{*}=13.92$. And we yield that the optimal profit of the supplier and the manufacturer is $\Pi_{Sn}^{CRS*}(k_{Cn}^{*})=112.229656$, $\Pi_{Mn}^{CRS*}(k_{Cn}^{*})=98.728344$. The efficiency of the supply chain is improved to 100%.

(4) Also, as they forge COS contract, we yield $\Delta=0.36$, $k_{Cn}^{*}=13.92$, $k_{Sn}^{*}=13.2$. If the supplier increases its capacity from k_{Sn}^{*} to k_{Cn}^{*}, he surfers profit loss as: $S_{Loss}=0.3888$. After the manufacturer compensate the supplier's loss, the manufacturer gets CO=0.648. If they have equal bargaining power in the sharing of CO ($\phi=0.5$), their profits are $\Pi_{Sn}(k_{Cn}^{*})=112.254$ and $\Pi_{Mn}(k_{Cn}^{*})=98.704$, and the efficiency of the supply chain is improved to 100%.

Table 1 Summary of the coordination of the supply chain with the contracts

0	Policy	k_{Sn}^{*}	k_{Cn}^{*}	Π_{Mn}^{*}	Π_{Sn}^{*}	Π_{Cn}^{*}	EC
(1)	Without coordination	10	12	17.5	11.25	29.75	96.64%
(2)	Long-term contract	13.2	13.92	98.38	111.93	210.31	99.69%
(3)	CSS (β, γ)	13.92	13.92	98.728344	112.229656	210.958	100%
(4)	COS (δ_p, ϕ)	13.92	13.92	98.704	112.254	210.958	100%

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4.2 Sensitivity Analysis

The demand is assumed to follow U [a,b], with the mean as $E(U)=10$. In the CRS contract, the partners share equal risk. And they share equal CO in the COS contract. Table 6 shows the summary of sensitivity analysis of the contracts with parameters.

Table 2 Sensitivity analyses of the contracts with demand variability

(p=7, *w*=4, c_l=1.5, c_p=1.0, c_m=1.0, n=5, $\alpha=0.2$)

Policy	Long term contract							CRS contract			COS contract			
δ	k_{Sn}^*	k_{Cn}^*	k_{Cn}^* - k_{Sn}^*	Π_{Mn}^*	Π_{Sn}^*	Π_{Cn}^*	EC	Π_{Mn}^*	Π_{Sn}^*	β	S Loss	CO	Π_{Mn}^*	Π_{Sn}^*
1	11.1085	11.3579	0.2494	99.4393	119.1660	218.8303	0.9990	99.5518	119.2785	0.4549	0.1285	0.2337	99.5613	119.2890
2	12.2170	12.7159	0.4988	98.8778	115.3308	214.6583	0.9979	99.1027	115.5556	0.4617	0.2581	0.4675	99.1126	115.5658
3	13.3255	14.0738	0.7482	98.3172	111.4968	210.4864	0.9968	98.6534	111.8330	0.4687	0.4000	0.6789	98.6628	111.8437
4	14.4341	15.4317	0.9977	97.7557	107.6616	206.3144	0.9957	98.2043	108.1102	0.4760	0.5296	0.9126	98.2141	108.1204
5	15.5426	16.7896	1.2471	97.1942	103.8264	202.1447	0.9944	97.7563	104.3885	0.4836	0.6715	1.1241	97.7643	104.3983

Table 2 shows the result of sensitivity analysis of the contracts with demand variability. We can find that the optimal capacity for the supplier and the chain, and their difference is increasing with the increasing of demand variance under long-term contract. Meanwhile, all the partners' profits and the channel efficiency are decreasing. With the CRS contract, the manufacturer has to share more capacity cost with the supplier to stimulate the supplier to build the channel optimal capacity. With the COS contract, the supplier's loss is increasing as he increases its capacity to the channel optimal capacity. Therefore, the manufacturer has to compensate more loss for the supplier. All the partners' profits are decreasing with the demand variance increasing as they forge COS contract.

Table 3 shows the result of sensitivity analysis of the contracts with unit capacity cost. Under the long-term contract, the optimal capacity of the supplier and the chain is decreasing. Also, the channel efficiency is decreasing with the increasing of unit capacity cost. To achieve channel efficiency, the manufacturer has to share more capacity cost with the supplier under the CRS contract. Also, the manufacturer has to compensate more profit loss to the supplier with the increasing of unit capacity cost under the COS contract. However, system efficiency is achieved.

Table 3 Sensitivity analyses of the contracts with unit capacity cost

(p=7, w=4, C_p=1.0, C_m=1.0, w=4, p=6, n=5, δ =3.0, $\alpha = 0.2$)

Policy	Long term contract							CRS contract			COS contract			
C_I	k_{Sn}^*	k_{Cn}^*	k_{Cn}^* - k_{Sn}^*	Π_{Mn}^*	Π_{Sn}^*	Π_{Cn}^*	EC	Π_{Mn}^*	Π_{Sn}^*	β	S Loss	CO	Π_{Mn}^*	Π_{Sn}^*
1.0	13.9491	14.4479	0.4988	99.2520	123.7697	223.3217	0.9987	99.4020	123.9197	0.4451	0.1818	0.3186	99.3901	123.9316
1.5	13.3255	14.0738	0.7482	98.3172	111.4968	210.4864	0.9968	98.6534	111.8330	0.4687	0.4000	0.6789	98.6628	111.8437
2.0	12.7020	13.6997	0.9977	97.0074	99.7839	197.9878	0.9940	97.6057	100.3822	0.4930	0.7096	1.2113	97.6142	100.3907
2.5	12.0785	13.3255	1.2471	95.3236	88.6323	185.8280	0.9899	96.2597	89.5684	0.5180	1.1203	1.8722	96.2657	89.5747
3.0	11.4549	12.9514	1.4965	93.2663	78.0428	174.0029	0.9845	94.6132	79.3897	0.5437	1.6103	2.7033	94.6182	79.3945

Table 4 shows the result of sensitivity analysis of the contracts with supplier's wholesale price. With the increasing of wholesale price, the optimal capacity of the supplier and the chain are increasing and their difference is decreasing under the long-term contract, which indicates that the channel efficiency is improved. Under the CRS contract, the manufacturer needs to share less capacity cost with the supplier in the increasing of the wholesale price. It indicates that higher wholesale price can enhance the coordination efficiency. Under the COS contract, the supplier's loss and the CO are decreasing in the increasing of the wholesale price. The channel efficiencies are achieved for both CRS and COS contracts,.

Table 4 Sensitivity analyses of the contracts with wholesale price

(p=7, Cp=0.5, C_I=1.5, C_m=1.0, n=5, δ =3.0, $\alpha = 0.2$)

Policy	Long term contract							CRS contract			COS contract			
w	k^*_{Sn}	k^*_{Cn}	k^*_{Cn} - k^*_{Sn}	Π^*_{Mn}	Π^*_{Sn}	Π^*_{Cn}	EC	Π^*_{Mn}	Π^*_{Sn}	β	S Loss	CO	Π^*_{Mn}	Π^*_{Sn}
2.5	12.3902	14.1758	1.7856	168.3721	62.7590	235.3496	0.9821	170.4813	64.8682	0.7244	1.5280	4.2330	170.4942	64.8777
3.0	12.9514	14.1758	1.2244	146.3643	87.0014	235.3496	0.9916	147.3562	87.9933	0.6261	0.8962	1.9935	147.3688	88.0031
3.5	13.3255	14.1758	0.8503	122.8965	111.4968	235.3496	0.9959	123.3746	111.9750	0.5242	0.5171	0.9635	123.3859	111.9860
4.0	13.5928	14.1758	0.5830	98.7633	136.1353	235.3496	0.9981	98.9888	136.3608	0.4206	0.2846	0.4510	98.9978	136.3741
4.5	13.7932	14.1758	0.3826	74.2900	160.8651	235.3496	0.9992	74.3872	160.9623	0.3161	0.1293	0.2092	74.3969	160.9749

Table 5 Sensitivity analyses of the contracts with the depreciation rate

(p=7, n=5, Cp=1.0, CI=1.5, Cm=1.0, w=4, δ =3.0)

Policy	Long term contract							CRS contract			COS contract			
α	k^*_{Sn}	k^*_{Cn}	k^*_{Cn} - k^*_{Sn}	Π^*_{Mn}	Π^*_{Sn}	Π^*_{Cn}	EC	Π^*_{Mn}	Π^*_{Sn}	β	S Loss	CO	Π^*_{Mn}	Π^*_{Sn}
0.10	13.7412	14.3232	0.5820	99.3024	128.1001	228.5659	0.9949	99.1857	119.8202	0.4529	0.2448	0.4090	99.1846	119.8213
0.15	13.5334	14.1985	0.6651	98.9175	124.6360	226.8416	0.9855	98.9362	115.7912	0.4608	0.3191	0.5323	98.9363	115.7911
0.20	13.3255	14.0738	0.7482	98.4941	121.1477	223.0343	0.9848	98.6534	111.8330	0.4687	0.4047	0.6744	98.6523	111.8340
0.25	13.1177	13.9491	0.8314	98.0322	117.6386	219.2273	0.9838	98.3375	107.9453	0.4767	0.4990	0.8332	98.3364	107.9464
0.30	12.9098	13.8244	0.9145	97.5318	114.1122	215.4214	0.9825	97.9881	104.1285	0.4848	0.6045	1.0065	97.9871	104.1295

Table 5 shows the result of sensitivity analysis of the contracts with the depreciation rate. The depreciation rate is an indicator of the speed of technology advancement of the facility. The higher the speed is, the higher the depreciation rate is. With the increasing of the depreciation rate, we find that the supplier□s optimal capacity and the channel optimal capacity is decreasing, and their difference is increasing. As a result, the channel efficiency is decreasing under the long-term coordination contract. With the CRS contract, the manufacturer has to share more cost with the supplier to stimulate it to build the channel optimal capacity. With the COS contract, the manufacturer has to compensate more profit loss to supplier with the increasing of the depreciation rate. All the partners□ profits are improved with the CRS and COS contracts, and the channel profit is maximized.

Table 6 Summary of sensitivity analysis of the contracts

Policy	Long term contract						CRS contract				COS contract			
	k^*_{Sn}	k^*_{Cn}	k^*_{Cn} - k^*_{Sn}	Π^*_{Mn}	Π^*_{Sn}	Π^*_{Cn}	EC	Π^*_{Mn}	Π^*_{Sn}	β	S Loss	CO	Π^*_{Mn}	Π^*_{Sn}
δ	↑	↑	↑	↓	↓	↓	↓	↓	↓	↑	↑	↑	↓	↓
CI	↓	↓	↑	↓	↓	↓	↓	↓	↓	↑	↑	↑	↓	↓
w	↑	↑	↓	↓	↑		↑	↓	↑	↓	↓	↓	↓	↑
α	↓	↓	↑	↓	↓	↓	↓	↓	↓	↑	↑	↑	↓	↓

Key for↑ : for increasing &↓ : for decreasing

5. Discussion and Conclusion

The uncertainty of the market demand and capacity makes the fashion goods supply chain too difficult to be coordinated. In practice, the long-term coordination contract seems to be valuable in discouraging opportunistic behavior. Repeated and ongoing interactions facilitate the development of trust and cooperation between firms. Indeed, while the importance of long-term, cooperative relationships is widely reported in practice, the supply chain literature has devoted comparatively little efforts in formally modeling this phenomenon in the capacity coordination issues.

This paper addresses the issue of capacity coordination in fashion goods supply chain. In our analysis, we assume that the demand of the fashion goods is stochastic, and the capacity cost is capital-intensive. The supply chain is a decentralized control structure, which is associated with the existence of an OEM manufacturer and a supplier. The supplier has to build the capacity before the realization of the final demand. To reduce the impact of demand volatility to their coordination, they share the demand information in real time. With the demand uncertainty and capacity expansion uncertainty, the supplier is conservative to expand to the channel optimal capacity. To achieve channel efficiency, the manufacturer should stimulate the supplier to build the channel optimal capacity. We show that the long-term contract can stimulate the supplier to build more capacity and improve the channel efficiency. However, the supplier's optimal capacity cannot achieve the channel optimality. The manufacturer has to involve into the supplier's capacity decision by sharing the capacity risk with the supplier to achieve channel efficiency.

We propose the CRS contract which can facilitate the coordination of the supplier and the manufacturer in repeated transactions. For managerial implications, the CRS contract can be used to explain why the OEM manufacturers in fashion industries always invest upstream suppliers. The investment mitigates its capacity risk, and ensures the supply. Also the COS contract coordinates the capacity decision in fashion goods supply chain. In this contract, the supplier's sharing of the coordination-overflow profit depends on its bargaining power with the manufacturer. CRS and COS contracts options are Pareto-optimal solutions for both partners, which ensures all supply chain partner firms take part in the coordination task voluntarily.

In our analysis, we assume that the information of market demand and capacity cost is symmetric to all the members. However, information asymmetric is common in practice. With the asymmetric information, CRS and COS contracts options can not be coordinate the supply chain's capacity decision for the cause of the moral hazard problem of the supplier. Clearly, this is a potential direction for future research. We believe that it maybe worthwhile considering the role of wholesale price negotiated by the partners when the manufacturer can control the retail price.

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Framework for DCM Strategy to reinforce SCM and Case Studies in Japan

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Abstract

Demand Chain Management (DCM) has lately attracted considerable attention from the view points, one is to reinforce SCM by paying more attention to information flow from customers to suppliers and another is to achieve quick product or process innovation by rapid and accurate collection for customers' needs.

In this paper, first of all, the characteristics and correlation of SCM and DCM are made clear by reviewing recent typical literatures. Secondly Demand Information which is the core of demand chain is sorted based on our precedent research. Simultaneously the important functions of enterprise are categorized from the view point of Value Chain. Then DCM Strategy Matrix with the results of these basic researches is built up and the concrete solutions on building DCM System are argued by using DCM Strategy Matrix. Thirdly the named Customer Information Service Center (CISC) is proposed. It should be set in the formation of DCM System to play the role of a router on demand information flow. A few concrete examples in Japan to explain the affection of CISC are given and the effectiveness of CISC is investigated. Finally, the Synergy Effect between SCM and DCM is demonstrated.

Value of Recovery Information in Closed-loop Supply Chain

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Abstract

In recent years, Information and Communication Technologies (ICT) are used to support Closed-loop Supply Chain networks. Most ICT system have been developed to address needs in several fields such as decision-making on different recovery options returns, designing a product for optimal end of use recovery etc. Recovery information is very useful for the decision-maker to decrease uncertainty in Closed-loop Supply Chain networks. In this study, we investigate the value of recovery information in closed- loop supply chain. As a result, we find that the recovery information is efficient for manufacturer, but it is not always efficient for supplier in closd-loop supply chain.

ROLE OF INSTITUTIONAL SUPPLY CHAINS IN THE DEVELOPMENT OF NEW INDUSTRIES: THE CASE OF INDIA

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ABSTRACT

This research examines the role of supply chain management as an institutional innovation strategy in the development of new industries in developing countries, such as India. It demonstrates that in new industries, firms with medium to high levels of supply chain management thinking, planning and implementation are more successful in terms of creating value and achieving competitive advantage than those with lower levels of supply chain management thinking, planning and implementation. The research identifies three types of supply chains in new industries. They have been labeled: Achievers, Idealists and Operators. Achievers, such as the Indian ICT (information & communication technology) industry, are the most successful and most advanced in terms of supply chain management thinking and practices. Idealists, such as the Indian petroleum industry, exhibit supply chain management thinking, but lack implementation of supply chain practices. Operators, such as the Indian leather and/or textile industry, do not have a supply chain orientation and create value and gain competitive advantage through their operational competencies. In terms of theory, the study shows that the use of supply chain management as a framework for analysis, and supply chains as units of analysis, benefits both institutional policy development and practice. The application of public sector funding to new industry development may provide greater dividends if a whole of chain approach is taken, as opposed to a focus on individual firms or industry sectors. Private sector managers, on the other hand, can utilize this same conceptual framework to assess their performance, and use the insights thus gained to improve their own supply chain management performance and thus their competitive advantage.

A framework for Logistics network design considering Inventories and Safety stock allocation

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ABSTRACT

Managing inventory is a major challenge for firms they simultaneously try to reduce costs and improve customer service. It consists of two critical tasks to determine the number and locations of stocking points and to determine the amount of inventory. The amount leads to a non-linear function of lead time. The first task is obtained by *the LND model* by using a piecewise linear approximation. The model gives a network configuration and concerns with long-term decisions faced by the firm about resource acquisition such as opening or closing new plants or distribution centers. The second task is obtained by *the safety stock allocation model* by using mainly dynamic programming. The model gives a lead time in the supply chain that is subject to demand or forecast uncertainly. We show a framework that is integrating LND and safety stock allocation models by incorporating lead time explicitly in the LND model.