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Value Delivery in Convergent Supply Network with Mediating Auctioneers

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Abstract: Value delivery is the ultimate objective of every supply network. In this study, we propose a method of mitigating the effects of excessive competition in a convergent manufacturing supply network. Using an auction based protocol; market equilibrium is reached for a resource allocation problem within the network. In order to improve the quality of the solution obtained, a mediation method facilitated by network auctioneers is proposed. This method will allow an auctioneer to redistribute cost in its market in such a way as to improve throughput in that market which ultimately improves the throughput of the supply network.

Keyword: Value delivery, Supply network

1. INTRODUCTION

The role of an auctioneer in market-based optimization models of manufacturing supply networks is more often than not, strictly that of a trade facilitator. Depending on the complexity of the network and the individual properties of the agents, satisficing solutions can be obtained. In this study, we propose auctioneers, which not only facilitate trades between sellers and buyers of manufacturing resources, but are also empowered with limited powers to influence the outcomes of trades in order to improve the global throughput of the supply network; thus improving the solution obtained from the supply network optimization model. A convergent supply network as described in this study is taken to mean a manufacturing supply network in which enterprise units that make up the network combine a number of input resources to produce their outputs. The proposed model divides the supply network into two sections – the value transformation section and the value consumption section. The value transformation section is made up of manufacturing enterprises that are responsible for producing resources in the supply network while the value consumption section is made up of pure consumers who trade their monetary endowments for final products of the value transformation section.

2. CONVERGENT SUPPLY NETWORK

Fig. 1 illustrates the organization of a typical convergent supply network. We treat the value transformation section of the supply network as a virtual enterprise [1] in which all participants have private goals of maximizing profit and a global goal of maximizing the throughput of the supply network. Every layer in the supply network is made up of multiple markets with each market having enterprise units producing a unique type of resource. An enterprise needs a combination of resources in a preceding layer to produce its own resource as shown in the figure.

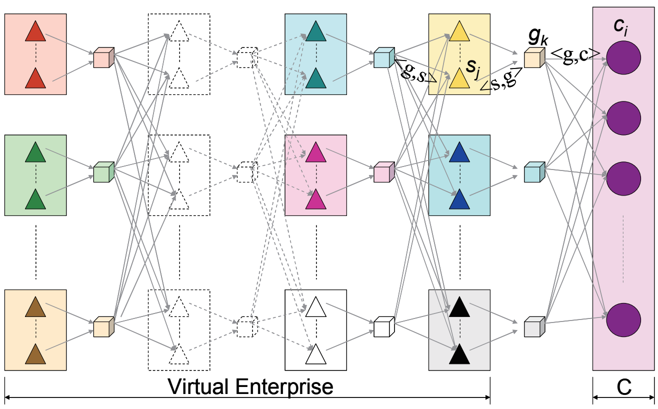

Fig. 1 Convergent supply network

3. VIRTUAL ENTERPRISE MODEL

From Fig. 1, the supply network is modeled as a graph H with all the enterprise units, consumers and goods making up the node set N while the arc set A represents connections between nodes.

H: (N, A); $N = T \cup G$ = nodes in graph H
T: $\{S, C\}$ = set of traders in H
G = set of market resources in H
A: $\{a_i = \langle g, t\rangle_i$ or $\langle t, g\rangle_i \mid t \in T;\ g \in G\}$= set of directed arcs
$\langle g, s\rangle$ = resource g is an input to enterprise s
$\langle g, c\rangle$ = resource g is consumed by consumer c
$\langle s, g\rangle$ = resource g is produced by enterprise s

The value delivery problem of the virtual enterprise is:

$$u((N^*, A^*)) = \max_{(N',A')\in(N,A)} (u((N', A')) \mid (N', A') \text{ is feasible}) \quad (1)$$

Given that

$$u((N', A')) = \sum_{c\in C} u_c((N', A')) - \sum_{s\in S} \pi_s((N', A')) \quad (2)$$

s.t.

$$u_t \geq 0; \quad \forall\ t \in T \ \ and \ \ g \in G \quad (3)$$

u = value accrued to an enterprise

π_s = production cost of enterprise *s*

The optimization problem defined in equations (1) – (3) is a value delivery maximization problem for the virtual enterprise. This problem is clearly combinatorial given that market resources are indivisible and are not grossly substitutable; but using combinatorial auction algorithm to find an optimal solution might prove inefficient especially with a large number of resources and enterprise units; therefore a competitive auction algorithm which seeks to obtain a satisficing solution is proposed. The final allocation of resources using this method greatly depends on the way supply network participants bid. We use a generalized Vickery auction as the trading mechanism for each of the markets in the supply network. Ordinarily in this type of auction, the auctioneers for all the multiple markets in the network only facilitate trades and have no effect on the way participants bid. While this method will find a solution which may be suboptimal, it is necessary to find a way of improving the solution obtained.

3.1 Auction Algorithm

The auction algorithm used to obtain a solution to the value delivery problem is based on simultaneous ascending price bid [2] in which traders are only allowed to review their bids upward. Selection of auction winner is based on the (k + 1) auction which is a type of Vickery auction designed for multiple units of market resources. All the auctions in the network continue to run concurrently until no trader in the market is willing to review its bid. This algorithm is listed below:

- ***Step 1:*** *Initialize all trading agents and virtual markets*
- ***Step 2:*** *Consumer agents send bids at current market price* (*Adjust bid if not winning*)
- ***Step 3:*** *Enterprise Agents inspect number of winning sales bid*
- ***Step 4:*** *Enterprise Agents check if there is enough inputs to meet winning sales bid* (*if not, adjust procurement bid upward and increment price for sales bid*)
- ***Step 5:*** *Auctions compute new market price for all resources and posts bid results privately using the (k+1)st price mechanism*
- ***Step 6:*** *If no bid revision for all agents auction clears else go to step 2*
- ***Step 7:*** *Terminate Auction*

The (k+1)st price mechanism is used at step 5 of the algorithm to compute the current market going price and how much quantity every of a resource every bidder will be allocated at that going price. The traders can then review their bids accordingly if their bidding tactics permit it. A market clearing point is reached when no trader is willing to review their bids at the current going price. The traders are then allocated the quantities of the resource they bid for at their bid prices. The advantage of the simultaneous ascending price trading mechanism is that it allows bidding to move in only a single direction thereby increasing the speed with which the system reaches equilibrium.

3.2 Bidding Policies of Traders

The two types of trading agents in the market are the consumers and the enterprise units in the different markets that make up the virtual enterprise. These traders continue tot review their bids according to the principle of individual rationality which forbids them to have a negative returns on trade. The bidding policies of these agents are defined as follows:

Consumer:

$$p_c(g_i) = p'(g_i) + \alpha_c \quad if \quad p(g_i) < p'(g_i) \tag{4}$$

for

$$g_i = \arg\max_{g_i \in G}(\min(e_c^{g_i}, p_c(g_i))) \tag{5}$$

s.t.

$$(e_c^{g_i} - p_c(g_i)) \geq 0; \quad \forall\ i \in G; \tag{6}$$

$p_c(g_i)$ = new bid price of consumer c for resource i
$p'(g_i)$ = current market price for resource i
g_i = bid quantity for resource i
α_c = price bid adjustment variable of consumer c
e_c^i = endowment of consumer c for resource i

Equation (4) is the price bidding tactic for the consumer agent. A consumer agent adjusts its bid price by a value α_c if its last bid price is not enough to make it win all the quantity of that input. It therefore bids above the current market price for that input. Equation (5) represents the quantity of an input a consumer agent will bid for at its current bid value. It bids such that it can get as much units as possible at the current bid price subject to its total valuation for that input. Equation (6) guarantees individual rationality on the part of the consumer agent.

Enterprise:

$$p_w^{i+1}(g_o) = \begin{cases} \max(A, B);\ \text{if } p_w^i(g_k) < p'(g_k) \\ p'(g_o) \qquad\qquad \text{otherwise} \end{cases} \tag{7}$$

$$A = (p_w^i(g_o) + \beta_w) \tag{8}$$

$$(\sum_{k=1}^{m_{l+1}} p_w^{i+1}(g_k) + c_k^w) \tag{9}$$

$$p_w^{i+1}(g_k) = \max(p'(g_k), p_w^i(g_k) + \alpha_k^w) \tag{10}$$

$$g_o = \arg\max_{g_o \in G_L \subset G}(p'(g_o)) \tag{11}$$

$$g_k = \arg\max_{g_k \in G_{L-1} \subset G}((p'(g_k) + c_k^w)) \quad \forall\ k = 1,2...m_{l-1} \tag{12}$$

s.t.

$$(\sum_{k=1}^{m_{l-1}} p_w(g_k) + c_k^w) \leq p'(g_o) \tag{13}$$

$p_w^{i+1}(g_o)$ = new bid price for output resource of enterprise w
$p_w^{i+1}(g_k)$ = new bid price for input k of enterprise w
$p'(g_k)$ = current market price of input resource k
β_w = sales bid price adjustment variable of enterprise w
c_k^w = overhead cost of procuring resource k for enterprise w
α_k^w = input bid price adjustment variable of k for w
g_k = bid quantity of enterprise w for input resource k
g_o = output resource bid quantity of enterprise w
m_{l+1} = total number of markets in input layer (l + 1)

Equation (7) is the price bidding function of an enterprise agent for its product (selling price). It updates this price whenever there is a change in the price of any of its inputs. Equation (8) is a producer's adjusted selling bid price while equation (9) is the adjusted selling price due to variation in the price of an input resource). The price bid for inputs is done in much the same way as in the case of a consumer agent as shown in equation (10). Equation (11) is the output quantity bid policy. Equation (12) is the quantity bid function for inputs and is determined by the number of units the enterprise agent is willing to sell at that point in time. The equation shows how an enterprise agent selects the suppliers of an input by considering the allocation that will minimize its average overhead cost, i.e. the most input at the cheapest cost. The constraint of equation (13) is the non-negative profit constraint.

4. EXPERIMENTAL SIMULATION

Using the supply network in Fig. 2, an experimental simulation was done to investigate the behaviour of the enterprise units in the virtual enterprise to know how much of resources they are able to deliver to the final consumers.

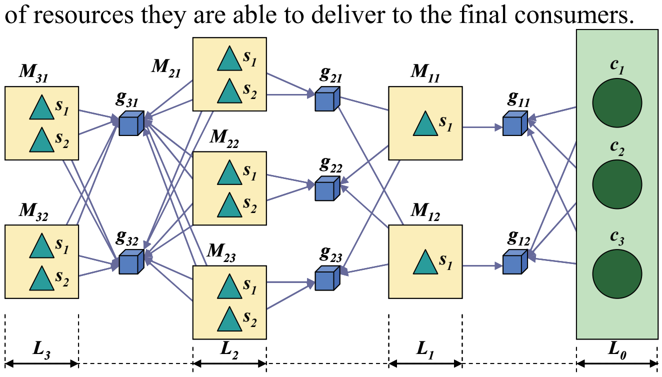

Fig. 2. Experimental supply network

In this network, we assume a resource combination ratio of unit across the network. By this we mean that every production enterprise requires one unit of all of their inputs to be able to produce their outputs; this is strictly for simplicity. Also, the bidding process in the virtual enterprise network is assumed to be synchronous and enterprise units bid for resources in bundles rather than in single units.

4.1 Resource Allocation

At the start of trading, an enterprise unit bids its maximum output with the hope of securing all the inputs it requires to meet the demand. However, as prices rise in its input markets and it has to bid higher for the inputs, it is possible for it not to be able to secure all its input at the current market price, therefore it drops quantity bid in its output market to the size of the lowest amount of input units it is able to secure. This method prevents a producer from winning output bids without being able to secure enough inputs. Hence, the output of producers decrease in response to market states until the market clearing point is reached.

Fig. 3 shows changes in the output quantity bids of enterprise units in the supply network as trade progresses.

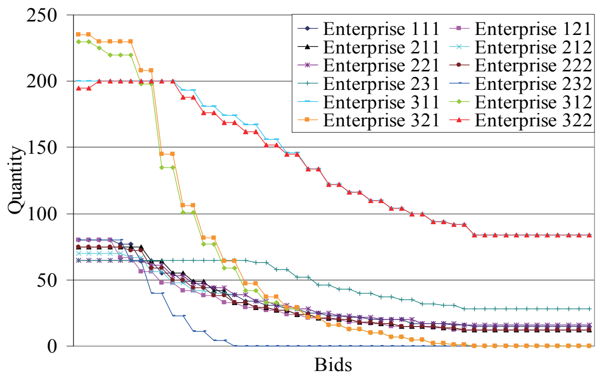

Fig. 3 Resource bids of enterprises in the virtual network

The resource allocation for the supply network is shown in Fig. 4.

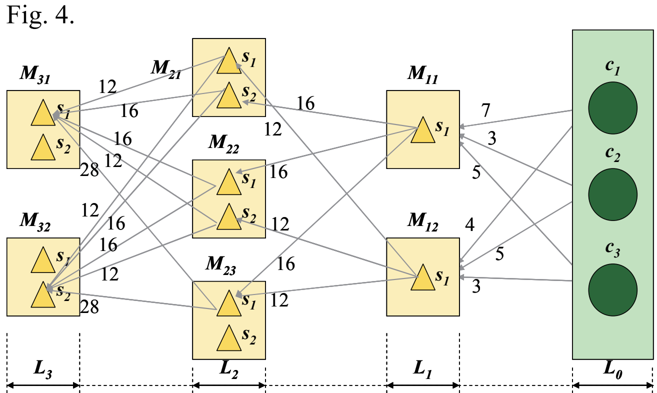

Fig. 4 Resource allocation in the supply network

4.2 Observations

Some observations have been made from several simulations done using different bidding parameters for the enterprise units. First, we define a supplier selection parameter that determines which supplier is selected by an enterprise from which market in the network.

Enterprise Selectivity

The term enterprise selectivity with respect to a suppliers' market is defined in this work as the relative preference of a producer for one of its supplier over other suppliers in that market. The enterprise selectivity for a supplier is a function of the competitiveness of that supplier from the perspective of the enterprise and the relative overhead cost of procuring inputs from the supplier. It is a measure of the relative advantage a particular supplier in a market has over other suppliers in that market with respect to it being selected by a prospective procuring enterprise. From equation (14), the two variables that determine the selectivity value are competitiveness (μ) and maximum overhead advantage (τ). Thus, we define an enterprise selectivity value $\zeta(\mu, \tau)$ of an enterprise k in layer u for one of its suppliers w in market v as a function of supplier competitiveness in equation (15) and maximum overhead cost advantage of supplier in (16):

$$\zeta_w^k = \frac{\mu_w^k \tau_w^k}{\sum_{s\in S_v} \mu_s^k \tau_s^k}; \quad |S_v| = a_v; \quad v \in M_{u+1} \tag{14}$$

$$\mu_k^w = 1 - (\alpha_k^w / \sum_{s\in S_v} \alpha_k^s) \tag{15}$$

$$\tau^{k}_{(s_1,s_2)} = \max((c^{k}_{s_1} - c^{k}_{s_2}),0) \qquad (16)$$

S_v = set of enterprises in market v

a_v = population of enterprises in market v

M_{u+1} = set of markets in layer $(u + 1)$

5. MEDIATING AUCTIONEER

For suppliers that are very competitive in terms of cost, i.e., enterprises find them more cost effective, their chances of winning the buy bids of buyers in their market is very high. With this in mind and considering the fact that there is a maximum output a supplier can sell at a given price, it means that if two enterprises find a supplier more favourable, they are likely to buy from the same supplier, therefore limiting the amount of resources that can flow through that supplier in the network. In such a case, the supplier serves as a bottleneck in the network. This can be seen in Fig. 4 where enterprise unit s_1 of market M_{23} is the sole winner of buy bids from the enterprises in layer L_1. This means that the two enterprises in layer L_1 find that supplier more attractive than supplier s_2 in the same market; therefore they are willing to buy all their inputs from s_1. This phenomenon is termed supplier dominance, which simply means that s_1 dominates s_2 in market M_{23} given the bidding parameters of prospective buyers.

In order to remove the bottleneck from the network, s_2 must become more attractive than s_1 to one of the enterprises of layer L_1. In order to achieve this, the only parameter that can be tinkered with is the overhead cost since part of it is a function of some environmental parameters like transportation cost, discounts etc. Therefore, if the overhead cost parameter of one of the enterprises in L_1 for resources from s_2 in M_{23} reduces to a certain point, that enterprise will find s_1 more attractive. The responsibility of adjusting this parameter can be given to the market auction. We term the type of auctioneers employed for this purpose as mediating auctioneers because the behaviour of the auctioneer is such that it holds part of the overhead cost of each allocation channel which may be in the form of third party logistics or outsourced inventory cost. When auction participants bid for products, the auctioneer distributes the overhead cost so as to favour participants in order of their feasibility. The goal of the mediating auctioneers therefore, is to improve the throughput of the network. Given that network participants would have to bid for resources with respect to their cost functions and private bid variation values, the quantity they bid for can be influenced over time by extraneous overhead cost imposed by the mediating auctioneer. When the extraneous overhead cost imposed on an enterprise unit increases relative to its competitors', it affects adversely its chances of winning the bids it places in that market. Thus, the auctioneer can tilt the outcome of an auction in the favour of more feasible enterprises. However, the influence of an auctioneer on auction outcomes is also controlled by the proportion of what overhead costs it has authority over. The higher the proportion the more its influence but the more biased the auction becomes; conversely, the lower the proportion, the lower its influence and the more competitive the auction becomes. In order words, the amount of controlling power given to the mediating auctioneer determines the relative balance between competitive behaviours of enterprise units and cooperation in the virtual enterprise.

We conducted an experiment in which one of the enterprises in L_1 finds s_2 of M_{23} more attractive and the allocation of the supply changed as shown in Fig. 5 and Table 1 shows a comparison with the previous allocation.

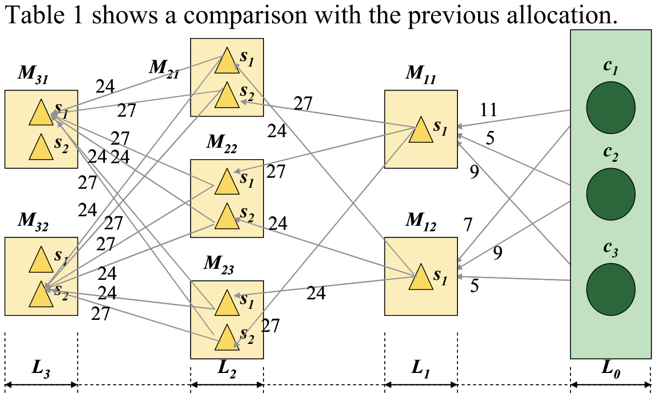

Table 1:

Consumer	Bottleneck in Network: Enterp. 1	Bottleneck in Network: Enterp. 2	No Bottleneck in Network: Enterp. 1	No Bottleneck in Network: Enterp. 2
C1	7	4	11	7
C 2	3	5	5	9
C 3	5	3	9	5
Tot. Output	**15**	**12**	**25**	**21**
Excess Input	3	0	6	9

6. CONCLUSION

The proposed method of using mediating auctioneers in an auction-based resource allocation mechanism to improve throughput of a supply network is a way to mitigate the effects of excessive competition in the network. By adding mediation to the responsibility of an auctioneer, an environment for cooperation among the various enterprise units in the supply network is created. The major challenge of this method however is the determination of how much mediating power an auctioneer should possess. Another area of further research is the modeling of the effects of mediation in a market on other mediating activities in other markets in the network.

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