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Product Swapping and Transfer Sales between Suppliers in a Balanced Network

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***Abstract*—In this paper we present a preliminary, deterministic mathematical model of cooperative supply chain network of suppliers and customers. We consider horizontal cooperation among suppliers such that they can swap their orders to reduce their transportation cost, and they can purchase products from each other to reduce their shortage cost. Hence, the objective is to examine the potential swap and horizontal purchasing operations between suppliers under perfect information sharing. Assuming a balanced network in a single-period, in which total capacity of suppliers is greater than or equal to the total demand of customers, we conduct an empirical analysis for six suppliers and eight customers. The analysis suggests for many suppliers the benefits of order swapping and lateral purchasing.**

I. Introduction

IN today's competitive environment, customer satisfaction is one of the most prominent performance measures for companies, especially for the ones that serve consumers. In order to increase customer satisfaction, companies might focus on increasing customer service level, responding orders quickly, shipping the right items in the right amount. To be able to achieve these, there are several classical strategies implemented by companies such as opening new depots or warehouses close to customers, increasing inventory levels at the stores including safety stocks, using fast transportation modes or less-than-truck load shipments, etc. However, these methods cause increase in logistics and supply chain cost, hence reduces competitiveness of the companies. Therefore, reference [1] discussed that implementing co-opetition strategies, which identifies the existence of competition and cooperation strategies among different companies, provide companies to maximize their individual profits. Hence, companies look for win-win scenarios by sharing information that has an important effect on competition and the success of cooperation strategies [2]. So, what might be an example of cooperation strategies for different companies or different branches of a company? Examples to these strategies in literature might be inventory sharing, inventory pooling, lateral transshipment, and order swapping and exchanging by sharing partial or full information. In this paper, we focus on order swapping and lateral transshipment.

Swapping can be defined as an agreement between businesses, which are competing or non-competing, exchanging shipping, production, assets or market position to reduce overall costs. Our main purpose and motivation of using order swapping is to provide reduction in transportation costs by shipping products to closer customers on behalf of each other. Details and assumptions of this operation is discussed in the next section.

There are very limited research about swap operations in the context of supply chain and logistics. Reference [3] is the most relevant study to our study. Reference [3] developed a multi period mathematical model that seeks for an efficient coordination of swap and exchange transactions between supply chain partners in the field of oil and petroleum industry. They assume perfect information sharing, known demand and sufficient production to meet customers' demand. Reference [4] discussed the possible benefits and risks of swapping commodities and capacity with competitors by giving real-life examples. For example, two different manufacturers in chemical industry, one located in USA the other is in Europe, agreed to swap their monomers to use in their polymer operations after verifying that the product is the same. Hence, both company saved tens of million dollars in logistics cost per year. They also mentioned that industries that produce textile, paper, iron and steel products might include potential savings by implementing swap strategies. Lateral transshipment strategy allows suppliers or retailers in the same echelon to pool their inventories in order to enhance lower inventory levels and costs while providing at least the required customer service level. [5] define two types of lateral transshipment according to the timing of transshipments: proactive and reactive. While proactive transshipment can be planned in advance, reactive transshipment is performed when needed, for example when a company stocks out or faces a risk of stock out. Almost all of the studies about lateral transshipment reviewed by reference [5] focuses on inventory problems in stock points or branches of the same company. However, we consider different, competing companies in our study. Because of this reason, we suggest readers to read detailed review on lateral transshipment in [5].

In the light of these references, we want to notice that the contribution this study is to integrate two effective cooperation strategies in a mathematical model of single echelon supply chain network. Hence, in Section II we present assumptions of our model and the model formulation. Then, we conclude our study with an empirical analysis of the developed model and discussion of the results and future research questions.

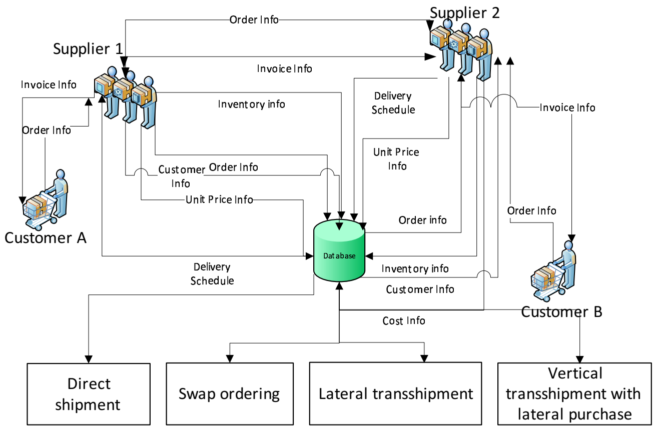

Fig. 1. Information system to generate shipping orders for suppliers in cooperation.

II. Model Assumptions and Formulation

In this study a single, commodity product network is examined which consists of a group of competing, but co-operating suppliers, where each supplier produces at their respective capacity which is known and constant. Customer demands are also known and constant. After customer sends their order requests to a supplier, the supplier share all the relevant data with other cooperating suppliers such as unit cost of purchase, unit market price, unit cost of transportation, inventory levels, location of customers and their orders. Hence, we assume pure information sharing among competing but cooperating suppliers. After all the data are processed and the mathematical model is utilized to generate the shipping orders to meet customer demands, there might appear four cases: direct shipment, swap ordering, lateral transshipment, vertical transshipment with lateral purchase (see Figure 1).

The demand at each supplier may be satisfied by shipping available on-hand inventory directly to a specific customer if there is no savings in swap ordering with another cooperating supplier. If swap decision is generated by the information systems, then the system sends swap orders to the suppliers that are going to ship the determined amount of products on behalf of each other to other's customer. Hence, the model aims to provide savings in transportation cost for both suppliers in cooperation by shipping products from closer suppliers to the customers. Here, we assume a balanced swap between two suppliers to construct equity between them such that each supplier should ship the same amount of product on behalf of each other. The appropriate documents and information flows among suppliers and customers flow as seen in Figure 1.

The suppliers share inventory and pricing information and might participate in an lateral transshipment arrangement in which every supplier must receive some benefit from the lateral transshipments. Because these cooperating suppliers are also competing each other, a lateral transshipment is realized only when a supplier that stocks out (called "dependant" hereafter) decides to purchase products from another supplier that has excess stock on hand (called "seller" hereafter). Due to lateral transshipment agreement, sellers should sell and ship the required amount to the dependants unless they face a stock out. In this preliminary model, we assume that the purchasing (or selling) price of the product between a seller and a dependant is deterministic and determined by averaging the unit market price of the dependant and the unit cost of the seller. In order to provide benefit to these suppliers, we assume that the unit market price of any supplier is greater than the unit cost of any supplier. This enhances that a dependant always buys products from other suppliers with a lesser price than its market price. While this pricing mechanism is relatively simplistic, it provides a standard policy to calculate the transfer price between suppliers. Even though this strategy aims to provide benefit to cooperating suppliers, it is still possible for shortage to occur if there is no benefit of purchasing excess inventory when cost of lost sales is less than total cost of purchasing and transportation between dependant and seller. The cost of lost sales is assumed to be the sales price of a product for that supplier. Additionally, there are no holding costs associated with excess inventory because this analysis only covers one period.

In vertical transshipment with lateral purchase agreement, if a dependant decides to purchase its need from a seller, he may require the seller to ship the product to its own customer if the customer is closer the seller than the dependant. Then, the dependant pays the cost of purchasing and the transportation cost to the seller. Hence, it can provide savings in transportation cost. In summary, the mathematical model we develop considers the sequence of cases we discussed above. First, suppliers decide if there is any benefit to executing a swap for their orders. If there is a benefit for two suppliers, a balanced swap occurs in which supplier i ships products to the supplier k's customer, and vice versa. If there is no benefit from executing a swap, the supplier ships directly to their customer. If a supplier's demand exceeds their inventory level, then that supplier seeks to purchase product from suppliers that have excess inventory. Then, he may either receive transshipments from other suppliers or the product may be shipped directly from seller to the customer on behalf of the dependant. Hence, the model parameters and variables are discussed as the followings.

The relevant parameters for the model are as follows:
c_{ij} :contracted unit transportation cost between supplier i and customer j.
D_{ij} : quantity demanded from supplier i by customer j.
I_i : inventory level on-hand at supplier i.
p_i : unit market price of supplier i.
u_i : unit cost of supplier i.
The model variables are as follows: q_{ij} : quantity shipped directly from supplier i to customer j.
b_{ij} : amount of lost sales between supplier i and customer j due to shortage.
y_{ijk} : quantity shipped from supplier i to customer j on behalf of supplier k due to order swap.
x_{ki} : quantity shipped from supplier k to supplier i due to

purchase by supplier i under lateral transshipment agreement.
w_{ijk} : quantity shipped from supplier i to customer j on behalf of supplier k due to purchase by supplier k under vertical transshipment with lateral purchase.
The upper bound of the cost of the i^{th} supplier (Z_i^u), which provides the worst case, is the total transshipment cost of the i^{th} supplier that ships to only its respective customers and its total cost of lost sales, if exist. The sum of Z_i^u for all suppliers is the upper bound of the cost of supply chain network (Z^u).

$$Z_i^u = \sum_{j=1}^{n} q_{ij}c_{ij} + b_{ij}p_i \tag{1}$$

$$\text{subject to} \tag{2}$$

$$\sum_{j=1}^{n} q_{ij} \leq I_i \tag{3}$$

$$q_{ij} + b_{ij} = D_{ij}, \forall i, j \tag{4}$$

$$q_{ij}, b_{ij} \geq 0. \tag{5}$$

Hence, the objective function of the model (Z) considers order swap and the lateral purchase among cooperating but competing suppliers if an excess demand exists.

$$\begin{aligned} minZ = & \sum_{i=1}^{m}\sum_{j=1}^{n}(c_{ij}q_{ij} + p_i b_{ij}) \\ & + \sum_{k=1, i\neq k}^{m}\sum_{i=1}^{m}\sum_{j=1}^{n}(c_{ij}y_{ijk} + c_{kj}w_{kji}) \\ & + \sum_{k=1, i\neq k}^{m}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\frac{u_k + p_i}{2}\right)w_{kji} \\ & + \sum_{k=1, i\neq k}^{m}\sum_{i=1}^{m}\left(t_{ki}x_{ki} + \left(\frac{u_k + p_i}{2}\right)x_{ki}\right) \end{aligned} \tag{6}$$

The first constraint is related to the inventory level for every supplier that is greater than or equal to the quantity shipped directly to their customers, the quantity shipped to other supplier's customers due to swaps, and the changes in capacity from the buying or selling of product from other suppliers.

$$\begin{aligned} \sum_{j=1}^{n} q_{ij} + \sum_{j=1}^{n}\sum_{k=1, k\neq i}^{m}(y_{ijk} + w_{ijk}) \\ + \sum_{k=1}^{m}(x_{ik} - x_{ki}) \leq I_i, \forall i. \end{aligned} \tag{7}$$

Demand for every supplier and customer relationship must be satisfied by shipment from supplier i, shipment from a different supplier due to swaps, the shipment of material sold to other suppliers to their customers, or lost sales.

$$q_{ij} + b_{ij} + \sum_{k=1, k\neq i}^{m}(y_{kji} + w_{kji}) = D_{ij}, \forall i, j. \tag{8}$$

Every swap must be balanced between two suppliers.

$$\begin{aligned} \sum_{j=1}^{n} y_{ijk} - \sum_{j=1}^{n} y_{kji} = 0, \quad & \forall i = 1, 2, ..., (m-1); \\ & \forall k = (i+1), ..., m; i \neq k \end{aligned} \tag{9}$$

Every supplier must benefit under the network swapping arrangement considering the costs for shipment from supplier i, shipment from a different supplier due to swaps, the cost of purchasing product from other suppliers, and cost of lost sales are less than or equal to its upper bound.

$$\begin{aligned} & \sum_{j=1}^{n}(c_{ij}q_{ij} + p_i b_{ij}) + \sum_{k=1}^{m}\sum_{j=1}^{n}(c_{ij}y_{ijk} + c_{ij}w_{ijk}) \\ & + \sum_{k=1, i\neq k}^{m}\sum_{j=1}^{n}\left(\frac{u_k + p_i}{2}\right)w_{kji} \\ & + \sum_{k=1, i\neq k}^{m}\left(t_{ki}x_{ki} + \left(\frac{u_k + p_i}{2}\right)x_{ki}\right) \leq Z_i^u, \forall i. \end{aligned} \tag{10}$$

Finally, quantity shipped directly, lost sales, quantities shipped to other suppliers' customers, quantities purchased by other suppliers, and quantities transshipped between suppliers must be non-negative.

$$q_{ij}, b_{ij}, y_{ijk}, w_{ijk}, x_{ki} \geq 0. \tag{11}$$

III. Numerical Investigation and Conclusion

A demand of a customer is randomly generated number between 100 and 1000 using uniform distribution. A supplier's capacity is also assumed to distribute uniformly between 1000 and 4000 such that total stock in the network is greater than the total demand of the network. Hence, a supplier observes either a shortage or an excess inventory. Excess inventory may be sold to a supplier facing shortage at a price between the seller's unit cost and the dependant's market price. Unit cost of products was generated between 300 and 330, and then market price of a supplier is generated by multiplying its unit cost by a uniformly generated profit margin between 10% and 30%.

The upper bound and the proposed model developed in the previous section run for a network of six suppliers and eight customers. As seen in Figure 2, every supplier receives some benefit either from the swapping or lateral transshipment agreement, or from both. Hence, the model provides benefit in transportation cost by a swap agreement and reduction in cost of lost sales by allowing cooperation among suppliers for their excess demand and supply in a single period. In order to investigate the effect of the proposed model on the supply chain network cost of each individual supplier, we aim to work on multi period with holding cost and partial information sharing.

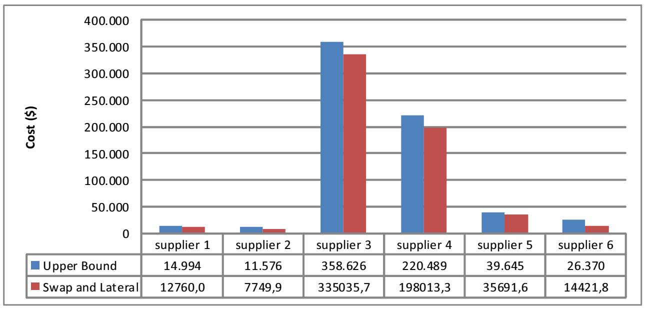

Fig. 2. Total transportation and backorder costs of each supplier with and without swap and lateral transshipment.

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