Effect of Sharing Supplier Capacity Information *

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Abstract

In recent years manufacturers have taken initiatives to integrate information within their supply chains in order to provide quick response to customer needs. In this paper, we study the influence of sharing supplier capacity information (available-to-promise capacity) on the performance of a supply chain. We consider a manufacturer who orders raw materials from two alternative suppliers differing in cost and capacity. We first derive the optimal inventory policy for the manufacturer under stochastic demand when exact capacities of the suppliers are known. Subsequently, using simulation, we compare different information sharing scenarios. Among other results, our simulation study shows that, while information sharing is beneficial to overall supply chain performance, it can be detrimental to individual entities. We find when supplier adoption costs of the information system are negligible, the more expensive supplier makes less profits under information sharing. However, it is still beneficial to share information for that supplier. When adoption costs are substantial, our results indicate that it is better for the manufacturer to have information links with fewer suppliers (a subset of potential suppliers).

1 Introduction

In a highly competitive market manufacturers face the challenge of reducing product development time, improving quality, and, reducing cost and leadtime for production. Their success in overcoming these challenges depends to a great extent on their ability to integrate individual plants (entities) into a tightly coupled supply chain. Management of material flow across several sites of the same enterprise is in itself quite challenging. This challenge is further complicated due to diverse (sometimes conflicting) interests of different entities in the supply chain. Recent studies [Helper and Sako(1995), Udo(1993), ECR(1993)] indicate that many manufacturers are sharing information (through inter-organizational information systems) with their suppliers to improve performance of the supply chain in terms of cost and customer service. However, the extent of benefits due to information sharing to different organizational entities is not well quantified. [Srinivasan et.al(1994), Cole and Yamakushiji(1984)] show in their empirical study that sharing information with suppliers led to a significant improvement in the performance of Chrysler and Toyota respectively. On the other hand, [Cash and Konsynski (1985)] indicate that inter-organizational systems (IOS) in many cases, under the guise of faster information flow shifted inventory holding costs and business risks to suppliers.

In this paper, we study the influence of sharing supplier capacity information through a computational study. First, we consider a manufacturer who procures components from two alternative suppliers while facing stochastic demand for a single product. Suppliers differ in terms of cost and available-to-promise (ATP) capacity. The more expensive supplier shows less variation in the capacity allocation as compared to the other supplier. We consider a discrete time single period problem where sequence of events is as follows- (1) Suppliers calculate the ATP quantity and assemble components to satisfy the ATP demand. (2) Manufacturer places an order with one or more suppliers. In case ATP information is shared then it uses that information while ordering; otherwise, it uses an approximation based on historical data. (3) Suppliers deliver the order in full or part based on the order size. They incur a holding cost for left over inventory and stock-out cost for unsatisfied demand (no backlogging). (4) Manufacturer converts raw inventory received from suppliers into finished products. (5) Demand occurs at the end of the period. Manufacturer uses finished products to satisfy demand. Holding cost is incurred on excess inventory (carried to next period) and stock-out cost for unsatisfied demand (no backlogging). We derive the optimal inventory policy that minimizes expected cost incurred by the manufacturer when capacities are known perfectly.

Subsequently through a computational study, we compare futuristic models with varying degrees of information sharing with models with no information sharing that reflect contemporary setting. In our computational study (with two suppliers), we simulate the inventory policy under a multi-period setting under different demand scenarios and capacity allocations by suppliers. It is to be noted that the policies are derived for single period problems and as a result are not optimal in a multi-period setting. However, we decided to simulate using the same policies because the optimal policies are intractable for multi-period problems and moreover, our main aim in the computational study is to try to understand the effect of information sharing on different entities as well as the overall effect. We compare performance in terms of costs incurred by the manufacturer, profits of suppliers and percentage of demand satisfied for alternative models of information sharing (of supplier ATP capacity)- (1) information links with both suppliers, (2) information link with one supplier and (3) information links with no supplier. Our results indicate that the supply chain (consisting of one manufacturer and two suppliers) performs better in terms of cost and quality of services (measured in terms of percentage of demand satisfied on time) under information sharing. We find that information sharing improves performance of the manufacturer and the less expensive supplier. We also find that the more expensive supplier may be forced to share information though information sharing is not of inherent advantage to that supplier. Subsequently, we analyze the impact of introduction of supplier adoption costs (cost to set-up and maintain information links). [Klein(1992) and Kelleher(1986)] indicate that manufacturers pay a subsidy (increase in price paid per component) to suppliers in order to compensate them for incurring additional investment for information sharing. The amount of subsidy (increase in price) is directly related to cost incurred by suppliers to adopt the information system. In our computational study, we vary the amount of subsidy given by the manufacturer in alternative models of information sharing. Our results indicate that if cost of adoption of the information system is relatively large (higher subsidy) then it is better for the manufacturer not to have information links with any of the suppliers. However, under lower adoption costs it is better for the manufacturer to set-up information links with one or both the suppliers. Further our results indicate that the manufacturer is more likely to maintain information links with suppliers when there is greater uncertainty in the supply process. Though our model is basic and most of our results are computational, we feel that the paper provides interesting insights with regards to sharing supplier information when addressed from different perspectives.

Literature related to supply chain analysis have indicated that dynamics associated with a supply chain can be extremely complex [Lee and Billington (1992)] and in most cases, can be empirically verified only through simulation. [Cohen and Lee(1988)] present a comprehensive approximation of a supply chain model that incorporates raw materials, production and a distribution system and provide valuable insight into dynamics of supply chains where demands are stochastic and all locations use reordering policies specified by two numbers (i.e. (s,S) or (Q,R)). [Pyke and Cohen (1994)] study a multiproduct integrated production-distribution system and discuss managerial insights that arise from the analysis. In this paper, we use simulation to study the influence of information sharing on the supply chain. Comparative analysis of diversification strategies for the manufacturer under supply uncertainty are discussed in [Moinzadeh and Nahmias(1988), Ramasesh et.al (1993), Lau and Lau(1994)]. [Anupindi and Akella(1993)] study a model where a manufacturer facing uncertain demand procures a component from two alternative suppliers. One of the suppliers is more expensive than the other in terms of cost but is more reliable in terms of delivery. The authors derive optimal inventory policy for the manufacturer under different scenarios (corresponding to shipments from suppliers) for single and multiple period problems. Our model is related to the above model, however, we additionally include capacity restrictions on suppliers and analyze the influence of information sharing in such a situation. Inter-organizational information systems have been studied predominantly using economic models [Riggins et al.(1994), Markus(1990)]. These models consider utility function of the user to join the information network. [Wang and Seidmann(1995)] use an economic model to study the influence of electronic data interchange (EDI) and its adoption by suppliers. They consider a downward sloping deterministic demand for the manufacturer. They find that it is optimal for the manufacturer to adopt EDI with fewer suppliers when the supplier adoption costs are high. Interestingly, in this paper we find a similar result in the computational study. In our problem, the manufacturer faces stochastic demand, shares ATP information and, optimizes ordering, stock-out and inventory costs.

The rest of the paper is organized as follows. In section 2, we develop a basic analytical model. We derive the optimal inventory policy. In section 3, we describe alternative models of information sharing and supplier adoption costs. In section 4, we discuss our computational results. In section 5, we present our concluding remarks and identify opportunities for future research.

2 Basic Model

In this section, we formulate a basic analytical model where the manufacturer has exact information about the capacity of suppliers, and derive the optimal inventory policy for the manufacturer.

2.1 Analytical Model

We consider a manufacturer who orders goods from two suppliers. It is very common for manufacturers to utilize dual sourcing because it provides the manufacturer the flexibility as well as generates competition between the suppliers thereby improving the delivery performance [Anupindi and Akella (1993)]. We assume that the suppliers differ in cost and the capacity allocated for the manufacturer. They can process the raw material immediately and supply components in the same period. However, they have a limited capacity which determines the (available-to-promise) ATP quantity. Typically, this is determined by the amount of demand that the supplier may have received from other manufacturer and how the supplier decided to allocate its capacity. It is perceived as a stochastic allocation by the manufacturer because it changes from period to period. We do not address the issue as to how capacity allocation is done at the supplier's end. In order to keep the analysis tractable we assume that for a particular manufacturer the allocation in each period is a random variable from a stationary distribution. The distribution corresponding to the less expensive supplier has more variance for the same mean value. To formulate the model more precisely, we use the following notations:

- ξ: random demand for the manufacturer in a period.
- C_i: available-to-promise capacity of supplier i in a period.
- p_i: cost of procuring the component from supplier i.
- x: on-hand inventory for the manufacturer at the start of a period.

- w_i: quantity ordered from supplier i in a period.

- γ_i: manufacturer's estimate of the maximum quantity that can be expected from supplier i.

- π: per unit per period stock-out cost for the manufacturer.

- h: per unit per period holding cost for the manufacturer.

- μ_i: mean of C_i.

- σ_i: standard deviation of C_i.

- $f(\xi)$: probability density of ξ.

- $F(\xi)$: cumulative density of ξ.

- $M(x, w_1, w_2)$: expected cost incurred by the manufacturer in a single period when the on-hand inventory is x and w_1, w_2 quantities are ordered from the suppliers.

We consider a single period model where the manufacturer minimizes expected cost incurred $M(x, w_1, w_2)$. $M(x, w_1, w_2)$ consists of- (1) cost of procuring the component from suppliers, (2) cost of carrying excess inventory or holding cost at the rate of h per item and (3) cost of falling short of the demand or the stock out cost at the rate of π per item. In any given period, the following sequence of events takes place. (1) Suppliers calculate the ATP quantity C_i and assemble components to satisfy the ATP demand. We neglect any kinds of gaming issues on the part of the supplier while providing the ATP information which could add additional dimensions to the above problem. In our model, we assume that perfect ATP information is transmitted to the manufacturer when information is shared. (2) Manufacturer places an order with one or more suppliers based on the current inventory level x and supplier capacity information. When ATP information is available the maximum amount that could be expected (γ_i) is C_i i,e $\gamma_i = C_i$. (3) Suppliers deliver the order in full or part based on the order size. They incur a holding cost for left over inventory and stock-out cost for unsatisfied demand (no backlogging). (4) Manufacturer pays for goods received and converts them into finished products. (5) Demand ξ occurs at the end of the period. Manufacturer uses the finished inventory to satisfy demand. Holding cost is incurred on excess inventory (carried to the next period) and stock-out cost for unsatisfied demand (no backlogging).

2.1.1 Single Period Cost Function for the Manufacturer

The expected cost incurred by the manufacturer is given by the equation below.

$$\begin{aligned}
M(x, w_1, w_2) &= p_1 w_1 + p_2 w_2 + h \int_{0}^{x+w_1+w_2} (x + w_1 + w_2 - \xi) f(\xi) d\xi \\
&\quad + \pi \int_{x+w_1+w_2}^{\infty} (\xi - x + w_1 + w_2) f(\xi) d\xi \\
&\quad w_i \leq \gamma_i \quad i = 1, 2
\end{aligned}$$

Lemma 2.1 : The single period expected cost function $M(x, w_1, w_2)$ is convex.

Proof: Since all the costs in the objective function are linear and since the feasible region is convex, the expected cost function is convex.

2.1.2 Inventory Policy for the Manufacturer

In this section we derive the optimal inventory policy for the manufacturer.

Lemma 2.2 : If the single period expected cost function $M(x, w_1, w_2)$ is convex then there exist numbers $w_{1a}^*, w_{2a}^*, w_{1b}^*, a$ and b such that the optimal procurement policy has the structure as follows :-

$$(w_1^*, w_2^*) = \begin{cases} (w_{1b}^*, w_{2a}^*) & if \quad x < b \\ (w_{1a}^*, 0) & if \quad a > x >= b \\ (0, 0) & if \quad x >= a \end{cases}$$

Proof: The single period cost function is equivalent to the problem where the procurement cost is piecewise linear convex increasing function. The optimal policy under such a function has the following structure [Porteus (1990)].

$$\begin{aligned}
a &= F^{-1}(\pi - p_1/\pi + h) \\
b &= F^{-1}(\pi - p_2/\pi + h) - \gamma_1
\end{aligned}$$

$$
\begin{aligned}
w_{1a}^* &= min(\gamma_1, F^{-1}(\pi - p_1/\pi + h) - x) \\
w_{1b}^* &= \gamma_1 \\
w_{2a}^* &= min(\gamma_2, F^{-1}(\pi - p_2/\pi + h) - x - \gamma_1)
\end{aligned}
$$

The policy indicates that there are three distinct regions in which the inventory could fall based on which the manufacturer decides to place orders with suppliers. In case the manufacturer has enough on-hand inventory ($x > a$), it does not place an order. If the on-hand inventory is more than b but less than a then orders are placed with the less expensive supplier and orders are placed with both suppliers if on-hand inventory is less than b.

On first glance, the policy may seem to indicate a relatively simple structure that advocates to buy as much as possible from the cheaper supplier and the rest from the more expensive supplier. However, on a closer look one finds that there exists a region such that $F^{-1}(\frac{\pi-p_2}{\pi+h}) - \gamma_1 < x < F^{-1}(\frac{\pi-p_1}{\pi+h}) - \gamma_1$ where the policy selects $w_1 = \gamma_1$ and $w_2 = 0$ though supplier$_2$ may have enough capacity to bring the inventory level to $F^{-1}(\frac{\pi-p_1}{\pi+h})$ (i,e $\gamma_1+\gamma_2+x > F^{-1}(\frac{\pi-p_1}{\pi+h})$). An intuitive explanation for this result is that once the manufacturer starts procuring components from supplier$_2$, the target inventory level changes to $F^{-1}(\frac{\pi-p_2}{\pi+h})$. However, in the above region $x + \gamma_1 > F^{-1}(\frac{\pi-p_2}{\pi+h})$, thus no orders are placed with supplier$_2$.

The above policy can easily be generalized to multiple suppliers. Let $a_1..a_N$ correspond to the N boundary points that define the reordering policy. For example, in a two supplier case, $b = a_2$ and $a = a_1$. Orders are placed with supplier i if the on-hand inventory is less than a_i. Let $\gamma_1..\gamma_N$ and $p_1..p_N$ correspond to the capacities and the prices of the N suppliers where p_1 is the least price. $w_1..w_N$ represent orders placed with the N suppliers. Then the above reordering policy can be stated as follows (note that $w_i > 0$ only when $x < a_i$):

$$
\begin{aligned}
a_i &= F^{-1}(\frac{\pi - p_i}{\pi + h}) - \sum_{j=1}^{i-1} \gamma_i \\
w_i &= min(\gamma_i, a_i - x)
\end{aligned}
$$

At each step, orders are placed with least cost supplier available and when the inventory level becomes higher than the order upto level for the supplier, no further orders are placed.

2.1.3 Inventory Policy for the Suppliers

In our computational study, we assume that the supplier produces up to the capacity allocated for the manufacturer. If the supplier gets an order less than the capacity allocated then it supplies the whole quantity otherwise it supplies up to the capacity allocated for the manufacturer. The supplier incurs a cost (which consists of cost of ordering, holding and stock-out) in each time period. We generate a random number from a stationary distribution to model the capacity allocation of the supplier for the manufacturer considered in the model. We restrict our attention to the cost incurred by the supplier due to that manufacturer. These cost figures help in the comparison of supplier's performance under different scenarios that are considered.

3 Variants of the Basic Model

In this section, we describe variants of the basic model that we compare computationally in this paper. The first three cases (Model-I, Model-II and Model-III) ignore supplier adoption costs and differ only in the extent of information sharing between the manufacturer and suppliers. Subsequently, we introduce price subsidies in Model-IIs and Model-IIIs to incorporate supplier adoption costs. It is to be noted that Model-II is the basic model described in section 2.

3.1 Extent of Information Sharing (Model-I, Model-II and Model-III)

Model-I (no information links) considers a manufacturer that does not have information (ATP) links with suppliers. Such a situation is very common in inter-organizational supply chains today. While making decisions on how much to order from each of the suppliers the manufacturer uses expected value of the capacity allocation as γ_i (maximum quantity that the supplier can be expected to fulfill). The manufacturer could employ a more sophisticated model for calculating γ_i if the statistical distribution of supplier allocations is available. However, the allocation depends on various exogenous factors and as a result the distribution is difficult to compute and is not available to the manufacturer. Typically, past performance of the supplier is utilized to place orders with it in the future [ECR(1993)]. In the absence of sophisticated data gathering techniques, manufacturer in industry tend to rely on the mean and variance of supplier performance. Since, the manufacturer does not utilize the exact information about the random capacity allocation by suppliers the policy derived in previous section is not optimal for this model.

Model-II (symmetric information links) considers a manufacturer that has information (ATP) links with both suppliers. Inter-organizational supply chains including grocery chains are striving to incorporate information systems which will enable quick and easy access of ATP and forecast information of other entities in the supply chain. In such an environment, the manufacturer knows supplier's capacity at the time of placing orders. This information is incorporated while calculating order quantities. The manufacturer changes the ordering policy in a dynamic fashion depending on the capacity allocation ($\gamma_i = C_i$) of suppliers. Since the information is perfect, the policy derived in the previous section is optimal for this model.

Model-III (asymmetric information links) considers a scenario where the manufacturer adopts information links only with the less expensive supplier. The rationale behind such a strategy is that the inventory policy of the manufacturer depends to a greater extent on C_1 than on C_2. The values of b, w_{1a}^*, w_{2a}^* and w_{1b}^* depend on C_1 whereas only w_{2a}^* and w_{1b}^* depend on C_2. The manufacturer could adopt such a setting when sharing information with both suppliers is not economically feasible or when the more expensive supplier refuses to adopt the information system. The reordering decisions are made with asymmetric information about the capacity allocations. Capacity allocation of the less expensive supplier is known exactly whereas the capacity allocation of the more expensive supplier is not known exactly. Here $\gamma_1 = C_1$ and $\gamma_2 = \infty$. This policy is optimal for the single period problem.

3.2 Price Subsidies (Model-IIs and Model-IIIs)

In this subsection, we briefly discuss various costs that have been attributed to adoption of information systems in the supply chain. Subsequently, we introduce two additional models that incorporate price subsidies for suppliers.

Adoption of a new technology such as electronic data interchange (EDI) leads to different types of costs [Hornback(1994)]. These costs can be classified into four major categories given below. (1) *Personnel*: These costs are related to hiring employees in order to maintain a information system. (2) *Training*: These costs are incurred during the initial phase of the adoption when major training sessions are conducted for the employees. (3) *Software*: Software costs mainly consists of purchasing, customizing and maintaining the software. Typically, the base price of software has reduced in the last few years. However, costs for customizing could be high in some cases when the translation software to interface with trading partner's proprietary information is expensive [Kelleher (1986)]. (4) *Communication*: Communication costs are costs incurred per transaction (time during which the phone line is utilized and the CPU time on the machine). Hardware costs are one-time set up costs that are incurred in the initial phase of the information system adoption. The costs of adoption of an information system for a supplier mainly consists of personnel and software costs. These include translation costs (from in-house to EDI format), security and syntax control, network services etc. Supplier adoption costs vary depending on the information systems already present with the supplier [Wang and Seidmann(1995)]. In practice, many large firms subsidize their suppliers for the cost of implementing information systems at least in the initial phases [Klein(1992)]. Subsidies can also be considered as means of profit sharing within the supply chain. These subsidies depend to a great extent on the initial cost of setting up and maintaining the information system.

We consider two additional models - Model-IIs and Model-IIIs which are similar to Model-II and Model-III described earlier. However, both Model-IIs and Model-IIIs include per unit price subsidies (δp) for suppliers who adopt information links. Thus, in Model-IIs there is a price increase for both suppliers ($p_i^s = p_i + \delta p$) and in Model-IIIs there is a price subsidy only for the less expensive supplier ($p_1^s = p_1 + \delta p$ and $p_2^s = p_2$). Our original motivation for considering adoption costs and price subsidies came from the observation that many manufacturers have extensive information links with their suppliers while others do not have such links. We conducted a computational study of our two-level model to get insights as to when manufacturers may have an incentive to adopt extensive links with their suppliers.

4 Computational Analysis and Insights

In this section, we describe our experimental setup and provide insights based on the results of our computational analysis. Before describing the details of our analysis we would like to indicate our analysis is based on a multi-period simulation (where inventory is carried over from one period to another) though the policies that we derived in the last section are for the single period problem. We use the same myopic policies in our simulation because multi-period model with stochastic demand and capacitated dual supply sources is an extremely difficult problem and as per the authors knowledge has not been studied in the past. For a single source of supply, previous research has shown that the multi-period problem has an order-upto optimal policy [Ciarallo *et al.* (1994), Wang and Gerchak (1996)]. However, even in their analysis it is shown that finding the optimal order-upto point could be extremely difficult. In addition, our aim in this analysis is to get insights on the effect of information sharing on the performance of manufacturer, both suppliers and the supply chain as a whole under information sharing and hence, we have tried to use myopic policies that are easy to utilize and implement.

4.1 Experimental Design

The demand distribution as well as the distribution functions of capacity allocations were assumed to be normal. In our study, we varied the standard coefficient of variation (scv = standard deviation/ mean) of demand and the standard coefficient of variation(scv) of capacity allocation of supplier_1 for different parameter settings of mean demand and mean capacity. For each of these scv value, the scv of capacity allocation of supplier_1 was changed from 0.125 to 0.375 (in ten equal steps). Supplier_1 is the cheaper supplier and hence shows more variability than supplier_2. Thus, scv of the capacity allocation of supplier_2 was set at 0.125 in all experiments. Each of these configurations was run 100 times, each time using a different set of seeds for random number generation. We ran each of the problems for 100 periods in a multi-period setting. Our results are based on a multi-period simulation where left over inventory is carried over from one period to another. It is to be noted that the policies used in our computations are not necessarily optimal for the multi-period problem. However, we utilize in the computations because these are simpler to utilize as compared to optimal multi-period policies which are intractable.

In all our experiments the holding cost per item of inventory per unit period for the manufacturer was set at 6% of the price per item of goods sold and for the suppliers at 10%. The stock-out cost for the manufacturer was set at 30% of the price of goods, whereas for the supplier_1 it was 13% and for supplier_2 it was 18%. The stock out cost of supplier_2 is higher because it is considered more reliable than supplier_1. Also, the manufacturer incurs a higher stock-out cost due to proximity to the end-customer. For example, one of the settings is shown in Table 1. Results discussed in tables 2-8 correspond to a particular setting of parameters shown in table 1 but we find similar results under other settings as well. Cost incurred at any site was measured as the sum of cost of purchasing raw materials, inventory holding costs and stock-out costs. Profits of suppliers were calculated at total revenue minus costs incurred. The total cost incurred in the system was calculated as the sum of the costs of manufacturer and suppliers minus the total procurement cost for the manufacturer. Performance of the model was measured in terms of the total cost incurred by the manufacturer, the system as a whole, profits of suppliers and the percentage of demand that was satisfied by the supply chain. We did not consider costs incurred by suppliers as a performance measure because their values are very small (because of the parameters values) and hence, they do not provide much insights.

4.2 Basic Effects of Information Exchange

We conducted a pilot study to understand the effect of information sharing on different entities in a supply chain as well as the overall performance of the supply chain. The scv of demand and capacity allocation of the supplier_1 were changed as described in section 4.1. We compared the performance of symmetric information sharing (Model-II) to no information sharing (Model-I). We find the following results:

- **Total cost incurred in the supply chain:** We define total cost incurred in the supply chain as the sum of costs incurred by suppliers and the holding and stock out costs incurred by the manufacturer. Our results indicate that - (1) An increase in demand variability increases the cost incurred for a given value for scv of supplier_1's capacity (refer Table 2). (2) Cost incurred increases with an increase in the variability of supplier_1's capacity for a given demand variability (refer Tables 3 and 4). (3) Cost incurred by the supply chain in Model-II is (10 to 14.8 %) less than the cost incurred in Model-I (refer Tables 3 and 4).

- **Quality of service provided:** Quality of service provided by the supply chain is measured based on the percentage of demand satisfied on time (Type-II service measure). Our results indicate that - (1) An increase in demand variability worsens the quality of service for a given value of supplier_1's capacity (refer Table 2). (2) Quality of service decreases with increase in the scv of supplier_1's capacity for a given value of demand variability (refer Tables 3 and 4). (3) Model-II outperforms Model-I consistently in terms of quality of service (increases 0.8 to 2.6 %) as shown in Tables 3 and 4.

An intuitive explanation for the above results is that uncertainty in the system either due to demand fluctuations, or supply fluctuations or lack of information leads to increase in cost and decrease in service.

- **Cost incurred by the manufacturer:** (1) Cost incurred by the manufacturer increases with increase in demand variability for a given value of scv of supplier$_1$'s capacity (refer Table 2). (2) An increase in the variability of supplier$_1$'s capacity increases the cost incurred by the manufacturer (refer Tables 3 and 4). (3) Cost incurred by the manufacturer is reduced by 2.2 to 5.0% in Model-II as compared to Model-I (refer Tables 3 and 4). Since in Model-II the manufacturer makes optimal decisions with more information the costs are lower.

- **Profits of suppliers:** (1) Profits of supplier$_1$ are greater in Model-II as compared to Model-I. The difference ranges from 10.1 to 15.0 % (refer Tables 3 and 4). It is to be noted that under information sharing, supplier$_1$ never incurs a stock-out cost because the manufacturer orders less than or equal to the capacity allocated. (2) Profits of supplier$_2$ are lower in Model-II as compared to Model-I. The difference ranges from 12.0 to 18.1% (refer Tables 3 and 4). One possible explanation for this result is that under information sharing the manufacturer completely exhausts that capacity of the first supplier before placing orders with the second supplier.

The above results indicate that supplier information sharing leads to better performance in the supply chain both in terms of cost and quality of service. However, supplier$_2$'s profits decrease with information sharing and as a result, we find that supplier information is *not* beneficial to all the organizational entities in the supply chain. In order to overcome the loss of business from the manufacturer as a result of information sharing, supplier$_2$ should improve the production process (this could be done with or without inputs from the manufacturer) so that it can produce at a lower cost. [Dyers and Ouchi (1993)] indicate that such situations are common in Japanese automotive industry where manufacturers like Nissan and Toyota often help a supplier to improve the production process.

4.3 Symmetric versus Asymmetric Information Links

From the results of the previous section, we find that the more expensive supplier's profits decrease in Model-II (refer Table 3). Competitive advantage of supplier_2 is the ability to deliver goods in a more reliable manner as compared to supplier_1. However, in Model-II this advantage of supplier_2 is lost because of the real-time information transfer that occurs between the manufacturer and suppliers. In such a situation, the manufacturer and supplier_2 have conflicting strategies. The manufacturer prefers information sharing (Model-II) whereas supplier_2 does not prefer information sharing (it prefers Model-I). This may result in asymmetric information links (Model-III) where, the more expensive supplier does not have information links with the manufacturer. We conducted the same set of experiments as in the previous section and compared the performance of Model-II and Model-III. On comparison of Tables 4 and 5, we find the following results -

- **Total cost incurred in the supply chain:** Total cost incurred in the supply chain is more in Model-III as compared to Model-II. The difference in cost incurred is less than 3 % for all values of scv of supplier_1's capacity.

- **Quality of service provided:** Percentage of demand satisfied on time is less in Model-III as compared to Model-II. The difference in most cases is less than 0.5 % of total demand.

- **Cost incurred by the manufacturer:** Cost incurred by the manufacturer is more in Model-II as compared to Model-III. The difference is marginal and in all cases is less than 0.1 %.

- **Profits of suppliers:** Profits of supplier_1 remain the same in both Model-II and Model-III. However, profits of supplier_2 is less in Model-III as compared to Model-II. An intuitive explanation for that being in Model-II the supplier never incurs stock-out costs because the manufacturer always places orders which are less than or equal to its capacity. Thus, it is better for supplier_2 to share information given that supplier_1 shares the information.

Our results indicate that asymmetric information links (Model-III) is worse for all the entities including the more expensive supplier. As a result, the more expensive supplier is forced to share the information because the less expensive supplier is inclined to share the information.

4.4 Supplier Adoption Costs

So far we ignored the supplier adoption costs which influenced our results indicating that both suppliers are inclined to share information. In practice, we generally do not find such situations where all entities in the supply chain unilaterally favor such a decision. In this section, we introduce supplier adoption costs in our analysis. On introduction of adoption costs it is not optimal for suppliers to share information when the adoption costs are greater than the increase in profits due to information sharing. In order to encourage suppliers to adopt the technology, the manufacturer may need to provide subsidies. However, these subsidies may drive the manufacturer towards not having information links if the adoption costs (and subsidies) are high.

In our computational study we performed the same set of experiments with different values for the subsidy ($\delta p = 0.01, 0.05, 0.1, 0.15, 0.20, 0.30$ and 0.50). Recall that the values of p_1 and p_2 in all our experiments are 4.5 and 5.5 respectively. It is to be noted that Model-IIs and Model-IIIs (described in section 3.4) are identical to Model-II and Model-III respectively when $\delta p = 0$. We find the following results (summarized in Tables 6, 7 and 8).

- (1) It is better for the manufacturer to have information links with both suppliers when price subsidies are low (compare the costs incurred for Model-I, Model-IIs and Model-IIIs when $\delta p < 0.05$).

- (2) It is better for the manufacturer to have information links with the less expensive supplier when price subsidies are moderate (compare the costs when $0.05 \leq \delta p < 0.5$ (for scv of supplier$_1$'s capacity = 0.25, 0.35) and when $0.05 \leq \delta p < 0.3$ (for scv of supplier$_1$'s capacity =0.15)).

- (3) It is better for the manufacturer to have no information links when price subsidies are high (compare the costs when $\delta p \geq 0.5$ (for scv of supplier$_1$'s capacity =0.25, 0.35) and $\delta \geq 0.3$ (for scv of supplier$_1$'s capacity = 0.15)).

Manufacturer's decision to adopt information links with the suppliers depends on the subsidy (δp) and the variation of supplier$_1$'s capacity allocation. When the subsidy value is low (supplier adoption costs are low) then it is better to have information links with both the suppliers. When the subsidy value is moderate then it is better to have information links with the less expensive supplier and when subsidy value is very high, it is better not to have information links. An intuitive explanation for the above result is as follows. Information exchange reduces the cost incurred by the manufacturer. The benefits of information sharing are more if the supply delivery process is more uncertain. However, as the costs for getting the information from the suppliers increase, it becomes optimal to selectively obtain the information. [Wang and Seidmann(1995)] show a similar result for a deterministic demand. They prove that if the supplier adoption costs for information links (EDI links) are high then it is optimal for the manufacturer to have EDI only with few suppliers. Our results provide one possible explanation for a supplier's preference to join the Commerce-NET and other WEB services (because supplier adoption costs are relatively low) whereas EDI links with specific manufacturers are not as prevalent (because supplier adoption costs are higher). We find from results (2) and (3) that the manufacturer is likely to maintain information links with suppliers when the uncertainty in the supply process is greater even if the supplier adoption costs are high.

5 Conclusions

In this paper, we analyze the effect of supplier available-to-promise (ATP) information on the performance of a supply chain. We integrate supplier information with the decision process of the manufacturer. We first develop a basic model for manufacturer/supplier interaction in a simple two-tiered supply chain, and derive an optimal ordering policy for the manufacturer. We then use the basic model (with two suppliers) to define a series of more specialized models, each making different assumptions about the extent and costs of supplier information exchange. Through our computational study, we have tried to understand the dynamics of the supply chain using different parameters for demand and capacity variations. We find that information sharing reduces the total cost incurred in the supply chain and improves the quality of service. These results confirm the belief that quick propagation of relevant information reduces uncertainty in the system and, as a result, leads to better performance. We find that the more expensive supplier may not benefit from information sharing, yet may be forced to share information. The less expensive supplier and the manufacturer benefit from information sharing (when supplier adoption costs are neglected). Thus, we find that inter-organizational information systems (IOS) may not be beneficial to all entities in the supply chain. Introduction of price subsidies (to model supplier adoption costs) changes the effect of information sharing on the performance of the manufacturer. We find that it may no longer be optimal for the manufacturer to share information with both suppliers. We also find that the manufacturer is likely to maintain information links with suppliers when uncertainty in the supply process is greater even if supplier adoption costs are high. Our results provide further insights into diversity of interests which lead to difficulties in the adoption of inter-organizational information systems in a supply chain.

Some of the possible extensions of this work are as follows. (1) A multi-period model for the manufacturer would facilitate understanding the relationship between performance of entities in the supply chain and number of periods in the decision process. In such a model, we need to incorporate that inaccuracy in capacity information for a future period increases as we move away from the current period. (2) In the basic model, we assume that suppliers face demand from other manufacturers as well. In most cases these manufacturers are part of the same industry. As a result, demand that the manufacturer (in our model) faces and capacity allocations of suppliers would be highly correlated. It would be interesting to analyze the impact of information sharing in such a situation. (3) Finally, multi-level modeling of the supply chain (with some approximations on the operating strategies) may provide additional insights on the impact of information sharing.

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	Mean Demand = 80			
	Mean Capacity	Holding Cost	Penalty Cost	Price of Goods
Manufacturer	-	\$ 3.0	\$ 15.0	\$ 50.0
Supplier_1	40	\$ 0.45	\$ 0.60	\$ 4.5
Supplier_2	40	\$ 0.55	\$ 0.90	\$ 5.5

Table 1: Cost and capacity values used in simulation.

	Model-I			*Model-II*		
SCV. of Demand	Total Cost	Man. Cost	Service (%)	Total Cost	Man. Cost	Service (%)
0.125	13357	48240	90.0	11823	47033	91.4
0.250	19203	52890	86.1	17934	51900	87.4
0.375	26063	58250	81.6	24900	57295	82.8

Table 2: Performance of the supply chain when scv of supplier$_1$'s capacity $= 0.25$

σ_1/μ_1	Total Cost	Man. Cost	Service (%)	Supplier_1's Profit	Supplier_2's Profit
0.15	18587	52319	86.7	16347	17384
0.20	19340	52788	86.1	15959	17488
0.25	20205	53334	85.4	15561	17568
0.30	21112	53917	84.7	15152	17652
0.35	21961	54465	84.4	14804	17700

Table 3: Performance of the supply chain under Model-I when scv of demand = 0.25

σ_1/μ_1	Total Cost	Man. Cost	Service (%)	Supplier_1's Profit	Supplier_2's Profit
0.15	16999	51381	88.4	17623	16758
0.20	17440	51620	87.7	17708	16471
0.25	17933	51900	87.3	17779	16180
0.30	18483	52221	86.7	17850	15886
0.35	19088	52591	86.4	17895	15607

Table 4: Performance of the supply chain under Model-II when scv of demand = 0.25

σ_1/μ_1	Total Cost	Man. Cost	Service (%)	Supplier_1's Profit	Supplier_2's Profit
0.15	17181	51417	88.2	17623	16612
0.20	17596	51638	87.4	17708	16333
0.25	18119	51929	87.2	17779	16030
0.30	18685	52265	86.3	17850	15729
0.35	19339	52670	86.1	17895	15436

Table 5: Performance of the supply chain under Model-III when scv of demand = 0.25

Subsidy (δp)	0.01	0.05	0.10	0.15	0.20	0.30	0.50
Model-I	52319	52319	52319	52319	52319	52319	52319
Model-IIs	51452	51894	52248	52602	52956	53664	55296
Model-IIIs	51457	51615	51813	52011	52209	52605	53397

Table 6: Comparison of cost incurred by the manufacturer for scv = 0.15 for supplier$_1$'s capacity and scv demand = 0.25

Subsidy (δp)	0.01	0.05	0.10	0.15	0.20	0.30	0.50
Model-I	53334	53334	53334	53334	53334	53334	53334
Model-IIs	51970	52401	52752	53102	53453	54154	55816
Model-IIIs	51978	52128	52328	52528	52728	53127	53926

Table 7: Comparison of cost incurred by the manufacturer for scv = 0.25 for supplier$_1$'s capacity and scv demand = 0.25

Subsidy (δp)	0.01	0.05	0.10	0.15	0.20	0.30	0.50
Model-I	54465	54465	54465	54465	54465	54465	54465
Model-IIs	52661	53088	53435	53782	54128	54822	54662
Model-IIIs	52710	52872	53072	53272	53475	53876	54681

Table 8: Comparison of cost incurred by the manufacturer for scv = 0.35 for supplier$_1$'s capacity and scv demand = 0.25