Information Systems and Coordination in Supply Chains

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Abstract
The evolution of information systems from transaction-oriented systems to more collaborative systems has created enormous efficiencies in supply chains and distribution channels. The performance of these supply chains depends critically on the rules for information sharing and governance of the relationships. We study a marketing channel with a single manufacturer and multiple retailers (a two tier supply chain) under different scenarios of inventory location and information sharing and investigate the effect on inventory, quantities ordered and on manufacturer’s profit, retailers’ profits and total channel profit.

1. Introduction

Information systems have had radical effects on supply chain structures, processes and strategies. Firms are increasingly collaborating with their partners to reduce inefficiencies in the procurement processes and extending supplier base (and for downstream activities, extending the distribution channels) globally [4, 6, 8, 10]. The basis of competition is increasingly moving from the firm level to the supply chain level. In this new environment organizations are increasingly collaborating with each other to increase the velocity of the material flow, reduce inefficiencies in the procurement/supply processes and reduce distortion of demand information as it moves upstream from retailers [5, 6, 15]. Such collaborations are emerging at different levels and depend on the technologies adopted by the supply chain members for supporting internal processes and for managing interactions at the boundaries. As the technology enables deeper process-to-process integrations, firms are moving from low level of integration, which involves simple exchange of procurement and payment data to synchronized supply where integrated planning and collaboration is put into place [8, 23], eventually leading to co-creation of value though joint innovation in products and processes [17].

As the collaborations in supply chains increase, governance of the relationship and profit sharing between supply chain members emerge as a critical issue. Different supply chain members have different incentives; a retailer who incurs inventory costs would focus on order quantity while a supplier who incurs production and scheduling cost would focus more on shipment schedules. Without proper incentives, members may be willing to hold back on critical information. An information sharing system that reduces lead-time uncertainty or variability in shipment quantity benefits downstream members but may not necessarily benefit the supplier, and thus create uneven incentives to adopt such systems [3]. In some cases, a simple information sharing mechanism may not lead to Pareto-optimal decisions and we might have to introduce additional mechanism(s) to achieve Pareto optimality [11].

In this paper we analyze a two tier supply chain with a single supplier and multiple retailers and examine the social and individual profitability under different collaboration mechanisms for developing forecasts and inventory locations. In particular we consider two distinct sources of uncertainty – one arising because of the global factors that affect overall reception of the product in market place and second that affect each retailer individually. A pre-market demand is estimated by the retailers and is passed on to the manufacturer who uses it to determine the global demand. In a centralized environment the estimates for the global demand can then be used to set the inventory levels for individual retailers, similar to a vendor managed inventory (VMI) system. In a bidirectional information sharing environment, the estimates of the global demand is passed on to retailers. They then incorporate it in
developing forecasts for their individual markets and set their individual inventory levels. In a completely decentralized environment with no information sharing, the retailers use only the initial demand estimates to set the inventory levels without any consideration for the global demand and the manufacturer follows with the production schedule based on the orders received. Under these scenarios we determine optimal inventory decisions.

2. Literature review

One of the key issues in supply chain management over last several decades have been management of inventory at different points in the chain in presence of demand uncertainty. Lack of transparency in the supply chain interactions leads each player to develop demand forecasts on the actual orders received, adjusted for its own understanding of the environmental uncertainties affecting the demand. Such subjective adjustments as the information moves up the supply chain can lead to a bull-whip effect, large distortions in perceived demand which in turn may lead to huge inventory costs due to excesses or shortages [15]. The earlier application of information technology in coordinating inter-organizational processes emerged in context of order processing systems. Using proprietary technologies and interfaces, American Hospital Supply Corporation’s ASAP system and McKesson’s Economost provided electronic links that their respective clients could use to place orders [9, 20]. While the aim of these systems was to improve operational efficiencies in the order taking process, AHS and McKesson ended up achieving significant competitive advantage. Not only their clients benefitted from these systems, but also time and effort invested by their respective clients in these propriety systems created incentive against switching to the competitors. Despite being hailed as strategic information systems in academic and practice literatures, these systems provided little process integration beyond the data capture at the boundary, any demand forecast developed by the suppliers were based on the transaction data. In many cases, the benefits of adopting such proprietary systems were asymmetric, with the initiator expropriating major share of the value generated by the systems. [19] Soon the success of these and other inter-organizational systems led to incorporation of technology in exchange of business data in wider contexts. These new systems moved away from proprietary technologies and were based on them emerging standards of Electronic Data Interchange (EDI) and UN/Electronic Data Interchange For Administration, Commerce and Transport (EDIFACT) and allowed parties on both sides of the transaction to interact electronically with wider set of partners.

First systems that led to sharing point of sale data and collaborative planning emerged in the retailing industry as continuous replenishment (CRP) systems. Quickly, the grocery industry followed with efficient consumer response (ECR) systems and apparel industry with quick response (QR) systems [7, 13]. These and many other initiatives have now converged into Collaborative Planning, Forecasting and Replenishment (CPFR) standards that allow the supply chain participants to shrink replenishment cycles, dynamically change product assortment, and in case of apparel industry implement rapid introduction of new products. In the automobile industry, EDI based supply chain management systems were initiated to automate many procurement processes and then later-on to transmit design changes and other engineering requirements to the suppliers [12, 19]. These systems allowed automobile firms to remove inefficiencies from their manufacturing processes and arrive at lean manufacturing, integrating material flows to multiple layers of suppliers, and implement CPFR based processes using electronic exchanges. In consumer electronics and computer industry, efforts to streamline supply chains led to Rosettanet, an industry wide consortium that developed XML based standards for product and process descriptions and later to standards in partner interface processes (PIPs) [21]. Rosettanet standards, competing ebXML standards and other similar standards have allowed for increased information sharing, multi-sourcing and postponement of the customization of the final product to the last steps of the value chain. As a result retailers like Dell were able offer product customization and very short order fulfillment cycle with only a few days of component inventory at hand [20]. Since then Rosettanet and ebXML standard have been adopted widely in many other industries. Standards also allowed buyers and suppliers to come together through electronic markets that may be independently owned and cater to many industries (e.g. Alibaba.com) or owned by an industry consortium and cater to the members of that industry (e.g., GHX). [1] (We may note here that the dot-com boom saw emergence of many business to business market places, many of which failed to survive, including Covisint in auto industry and Chemdex in chemical industry.) In merchandizing industry we have seen emergence of sourcing agent like Li & Fung that allow retail chains like Bed Bath and Beyond to reach out to suppliers in many countries
and if necessary use connectivity and tools provided by Li & Fung to design its products collaboratively with its suppliers [16]. Collaborative supply chains that integrate processes across firm boundaries provide much larger benefits than simple B2B commerce [18, 19]. However the benefits are not achieved evenly by all participants; as pointed out by Zhang et al., an information receiver always gains from information sharing systems but the information provider may not gain in all situations [24]. Often a dominant player in the supply chain will initiate the adoption a particular technology standard and/or system there by forcing its partners to adopt the system. A case in point is Wal-Mart who insists that its suppliers use its proprietary system, Retailink for order taking and invoicing processes. Intel’s early adoption of Rosettanet standards forced OEMs who were using its microprocessor chips to move to Rosettanet standards. In such cases the cost of adopting proprietary system may preclude a small player from adopting the system, especially if it planning to collaborate with others in the industry group. Even when there is no specific power relationship in the supply chain, the private optimization of price and quantity may lead to suboptimal decision and may require additional contractual arrangements to improve the overall performance.

3. Research Model

In this work we model the role of information systems in managing introduction of a new product for which there is not enough historical data. Such a case often becomes quite challenging as an innovation in the product or service may or may not be well received by the consumers. Often when a new model comes into the market, for example a TV model is released based on a new technology; there is little historical data to determine if the product will be appealing enough for consumers to replace their existing sets. In the apparel industry, the fashion house may have little idea on how the product will be received in the market place. In some cases the producer may use a short pilot program, alone or in conjunction with retailers, to determine the reception to the product and based on the results of the pilot, develop long term forecasts and inventory plans. In other cases, the producer may want to use the subjective and informal forecasts by its retailers to improve its understanding of the market. Note that unless the entire production and distribution channel is under a common ownership, each player bases its inventory decisions on its own forecast (formal or informal.)

We consider a simple two tier supply chain with a single manufacturer and multiple retailers. The retailers operate in independent markets (so that a sale is lost if a retailer faces stock out condition in its market.) We analyze the benefits of information systems linking supplier to retailers. The information system is used to transmit orders by individual retailer but can be also used to transmit demand information which is then used by the respective player to reduce demand uncertainty. This work builds on the quick response (QR) system developed by Iyer and Bergen [11], with the major difference that we allow for multiple retailers who in presence of an information system provide a tentative forecast that can be used to reduce the uncertainty faced by the manufacturer and/or by all retailers before finalizing their orders. The assumptions are as follows:

Inventory Location: We assume that the inventory location and inventory planning are coupled. If manufacturer plans for inventory then it is located with manufacturer. If retailers individually plan for inventory then it is located with retailers. However, if the manufacturer holds the inventory, then the manufacturer pools the demand from all retailers and makes plans based on the aggregate demand.

Demand Characteristics: The product is assumed to be a new product (e.g. a fashion good) with little demand information from the past. The demand in each of the retailer’s market is assumed to be independent and normally distributed as \( x_1, x_2, x_3 \ldots x_n \) in each of the \( n \) markets; \( x_1, x_2, x_3 \ldots x_n \) follow a normal distribution \( N(\mu, \sigma^2) \). The mean itself is unknown at the start of the season because of the lack of past data and the volatility of the market from season to season. The uncertainty in \( \theta \) arises from the fact the product or style or model is fairly new and therefore it is unknown how well the product is going to be received by the market. We assume that the mean \( \theta \) has a prior distribution \( \theta \sim N(\mu, \tau^2) \) and this distribution is known to the manufacturer and the retailers. Thus \( \tau \) reflects uncertainty over the entire population and \( \sigma \) reflects uncertainty in individual markets. This assumption is similar to the one made by Iyer and Bergen for demand distribution in a two echelon supply chain with a single retailer and follows standard stochastic model in Berger [2]. The joint distribution for the demands faced by the retailers are then given by

\[
 f(x_1, x_2, x_3 \ldots x_n, \theta)
\]
Planning Horizon – consists of two periods. The first period is a preseason when the market development efforts are undertaken. At the end of this period each retailer develops its individual forecasts and informs the producer. The information system for order taking is assumed to be error free so that no additional uncertainty is introduced in the system. Upon receiving the individual forecasts, the manufacturer develops a global forecast for the demand. However the subsequent steps of determining actual inventory depend on the information system and the decision allocation mechanism. We consider three distinct scenarios:

Scenario 1. There is an information system that allows flow of demand forecast only from retailers to suppliers and there is a point of sales systems that ties the retailers and manufacturer together on a real time basis. In this case the manufacturer bases its production schedule on the aggregate forecast and is responsible for managing inventory at the retailer site. The manufacturer is able to adjust the inventory levels (at retailer sites) in real time. Thus any stock out happens because of the aggregate realized demand exceeds the forecast.

Scenario 2. There are no information systems allowing flow of forecasts in either direction. Thus the only demand related information flows are the actual orders that retailers place with the manufacturer. Upon receiving these orders, the manufacturer produces just enough to meet the demand from retailers; once the production is complete, the shipment to each retailer takes place as one lot (i.e., there is no partial order fulfillment.) The manufacturer is not left with any excess inventory after the order fulfillment; any cost of inventory excess or shortage is then borne by the retailers.

Scenario 3. There is an information system that allows for bidirectional flow of demand information. Once the manufacturer gets the initial forecasts and develops pooled demand, it passes the forecast back to all retailers. Retailers then place orders based on this pooled demand and manufacture sets the production lot to meet these revised orders. Once the production is complete, the shipment to each retailer takes place as one lot (i.e., there is no partial order fulfillment. The manufacture is not left with any excess inventory after the order fulfillment; any cost of inventory excess or shortage is then borne by the retailers.

4. Pooled demand

When the pre-season demand from each of the retailers has been observed, the manufacturer can pool the demand information and generate a posterior estimate of $\theta$ as follows:

$$
\hat{\mu} = E(\theta| x_1, x_2, x_3, \ldots, x_n) = \frac{\tau^2}{n\tau^2 + \sigma^2}
$$

and

$$
t^2 = \text{revised variance of } \theta = \frac{\sigma^2 + \tau^2}{n\tau^2 + \sigma^2}
$$

We can see that as more retailers join the network and pool in their pre-season demand, the uncertainty as to the global reception of the product reduces. The posterior probability density function for $\theta$ the mean value of demand is [2]:

$$
g(\theta|x_1, \ldots, x_n) = \frac{1}{\sqrt{(2\pi t^2)}} e^{-\frac{(\theta-\hat{\mu})^2}{2t^2}}
$$
In the following we replace observations \( x_1 \ldots x_n \) by the sufficient statistic \( s = \sum x_i \) and use \( g(\theta|s) \) as the posterior density function for \( \theta \). The posterior distribution of the aggregate demand faced by the manufacturer after the initial estimates are reported by the retailers is then given by:

\[
g(\Phi|s) = \frac{1}{\sqrt{2\pi\hat{\rho}^2}} e^{-\frac{(\Phi - n\hat{\mu})^2}{2\hat{\rho}^2}}
\]

where \( \hat{\rho}^2 = \sigma^2 + \tau^2 \)

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As \( \tau < \tau \) and hence \( \hat{\rho} < \rho \) for all \( n \), sharing demand information with its peers, each retailer sees a reduced uncertainty. This is where the manufacturer comes in as the coordinator of the pooled demand information via a shared information system.

5. Inventory decisions

Given the information available to the manufacturer and the retailers and the decision rules, we can now determine the optimal inventory levels for the each scenario and the corresponding profits for each scenario. The cost and the price in all cases are assumed to be same and are given by

- The final retail price per unit is \( r \)
- The intermediate price at which the manufacturer sells to the retailer is \( w \) per unit
- The manufacturing cost is \( c \) per unit
- The cost of excess inventory at the end of the season to the manufacture is \( h \)
- The shortage cost per unit of lost sales for the manufacturer is \( p \)

- The cost of excess inventory at the end of the season for the retailers is \( h' \)
- The shortage cost per unit of inventory for the retailers is \( p' \)

The calculation for each case follows the standard stochastic inventory model, given the demand distribution. See for example [2].

**Scenario 1**

In this case all the inventory decisions are made by the manufacturer; retailers are just conduit to the customers. The manufacturer holds all excess inventory and any stock out happens because of a global stock out. The manufacturer then chooses to set the production level \( Q \) to maximize its profit given by:

\[
\pi_m = \int_{-\infty}^{\infty} w\Phi g(\Phi|s)d\Phi + wQ \int_{Q}^{\infty} g(\Phi|s)d\Phi
\]

\[
- h \int_{-\infty}^{Q} (Q - \Phi)g(\Phi|s)d\Phi
\]

\[
- p \int_{Q}^{\infty} (\Phi - Q)g(\Phi|s)d\Phi - cQ
\]

This is a standard news boy problem. The corresponding optimal quantity is given by

\[
Q_{opt,m} = n\hat{\mu} + z(k)\sqrt{n\hat{\rho}^2}
\]

where \( k = \int_{-\infty}^{z(k)} \varphi(y)dy = \frac{w + p - c}{w + p + h} \) is the optimal service level from the producers perspective and \( \varphi(y) \) is the standard Normal probability density function. The profit for the manufacturer is then given by

\[
\pi_{m,\hat{\mu}}(1) = (w - c)n\hat{\mu} - (w + h + p)\sqrt{n\hat{\rho}^2} \varphi(z(k))
\]

where \( \varphi(z(k)) \) is the density function at \( z(k) \). The expected profit is then obtained by taking expectation over \( \hat{\mu} \) and is given by

\[
\Pi_m(1) = (w - c)n\mu - (w + h + p)\sqrt{n\hat{\rho}^2} \varphi(z(k))
\]

The expected quantity sold is

\[
Q_{exp}(1) = n\mu + z(k)\sqrt{n\hat{\rho}^2} - \varphi(z(k))\sqrt{n\hat{\rho}^2}
\]

\[
- kz(k)\sqrt{n\hat{\rho}^2}
\]

The last two terms correspond to expected unsold inventory (which with our assumptions is held by the manufacturer.) The expected profit of the retailers is:
The expected channel profit is:
\[ \Pi_c(1) = \Pi_m(1) + \Pi_r(1) = (w - c)n\mu - n(r + h' + p')\rho \varphi(z(k')) \]

As the manufacturer produces to order, the manufacturer’s expected profit is:
\[ \Pi_m(2) = n(w - c)q_{opt} = n(w - c)\mu + nz(k')(w - c)\rho \]

The expected channel profit is:
\[ \Pi_c(2) = \Pi_m(2) + \Pi_r(2) = (r - w)n\mu + nz(k')(w - c)\rho - n(r + h' + p')\rho\varphi(z(k')) \]

The expected unsold inventory at each retailer is
\[ q_{r,unsold}(2) = kz(k')\rho + \varphi(z(k'))\rho \]

**Scenario 2:**

In this case there is no information sharing. The retailers’ orders are based on local forecasts at the beginning of the season and the manufacturer’s production plans are based on these orders. In this case manufacture follows a produce-to-order approach. Each retailer, at the time orders are placed, faces a demand \( x \sim N(\mu, \rho^2) \) where \( \rho^2 = \sigma^2 + \tau^2 \). Each retailer then sets the inventory level to maximize its profits given by

\[ \pi_r = \int_{-\infty}^{q} rxf(x)dx + \int_{q}^{\infty} rxf(x)dx - h'\int_{-\infty}^{q} (q - x)f(x)dx - p'\int_{q}^{\infty} f(x)dx - wq \]

The optimal quantity ordered by the retailer is
\[ q_{opt} = \mu + \rho z(k') \]

The retailer’s profit is
\[ \Pi_r(\hat{\mu}) = (r - w)\mu - (r + h' + p')\rho \varphi(z(k')) \]

Where \( k' = \int_{-\infty}^{z(k')} \varphi(z)dz = \frac{r + p'}{r + p' + h'} \) is the optimal service level from retailers’ perspective.

The expected profit for each retailer is:
\[ \pi_r(q_{opt}) = (r - w)n\mu - (r + h' + p')\rho \varphi(z(k')) \]

Using i.i.d. assumption, the expected profit for \( n \) retailers is:

\[ \Pi_r(1) = (r - w)[n\mu + z(k')\sqrt{n\rho^2} - \varphi(z(k'))\sqrt{n\rho^2} - k z(k')\sqrt{n\rho^2}] \]

The expected unsold inventory at each retailer is
\[ q_{r,unsold}(1) = k z(k')\rho + \varphi(z(k'))\rho \]

**Scenario 3:**

This is the case where there is an information system that feeds demand information from the retailers to the manufacturer and then the pooled demand back to the retailers. Retailers revise their forecasts correspondingly and place orders. The manufacturer’s production plans are based on these orders. In this case also manufacture follows a produce-to-order approach. At the time orders are placed, each retailer faces a demand \( x \sim N(\hat{\mu}, \hat{\rho}^2) \) or the density function \( m(x|s) \) and therefore sets the inventory level to maximize its profits given by

\[ \pi_r(\hat{\mu}) = \int_{-\infty}^{q} rxm(x|s)dx - \int_{q}^{\infty} rrm(x|s)dx - h'\int_{-\infty}^{q} (q - x)m(x|s)dx - p'\int_{q}^{\infty} (x - q)m(x|s)dx - wq \]

The optimal quantity for the retailer is:
\[ q_{opt} = \hat{\mu} + \hat{\rho} z(k') \]

The retailer’s profit is
\[ \Pi_r(\hat{\mu}) = (r - w)\hat{\mu} - (r + h' + p')\hat{\rho} \varphi(z(k')) \]

Where \( k' = \int_{-\infty}^{z(k')} \varphi(z)dz = \frac{r + p'}{r + p' + \hat{h'}} \) is the optimal service level. Note that optimal the service level is same as in Scenario 2.

And considering all probable values of \( \hat{\mu} \)
\[ \pi_r(3) = (r - w)\mu - (r + h' + p')\hat{\varphi}(z(k')) \]

The expected profit for n retailers is:
\[ \Pi_r(n) = n(r - w)\mu - n(r + h' + p')\hat{\varphi}(z(k')) \]

Expected inventory at each retailer is:
\[ q_{r, unsol}(3) = k'z(k')\hat{\varphi} + \varphi(z(k')\hat{\varphi} \]

In this scenario, similar to Scenario 2, the manufacturer produces to order and therefore manufacture’s expected profit is:
\[ \Pi_m(3) = \text{Exp}_{\mu}(\Pi_{m,\hat{\mu}}(3)) = (w - c)n\mu + (w - c)n\hat{\varphi}z(k') \]

The total expected channel profit is:
\[ \Pi_c(3) = \Pi_m(3) + \Pi_r(3) = n(r - c)\mu - n\hat{\varphi}(r + h' + p')\varphi(z(k')) + n\hat{\varphi}(w - c)z(k') \]

6. Comparison of profits under different scenarios

While the expected quantity ordered in all three cases will be above the average \( n\mu \), the manufacture’s profit in Scenario 1 is below \( (w - c)n\mu \) as it is forced to absorb the shortage and excess costs. When the inventory levels are set by the retailers and the retailers are forced to absorb the shortage and excess costs, the manufacture’s profit is above \( (w - c)n\mu \); and it is better off if there is an information system that allows the retailers to base their orders on pooled demand (\( \hat{\varphi}^2 = \varphi^2 / (1 + n\tau^2 / \sigma^2) < \varphi^2 \) or \( \hat{\rho}^2 < \rho^2 \) and therefore \( \Pi_m(3) < \Pi_m(2) \)). Thus the manufacturer has no incentive to adopt an information system that leads to better forecast, if as a result of that forecast, it is forced to absorb the inventory risk, but if must, then it is better off by sharing forecasts with retailers and then follow a “make to order” strategy. We also note that in Scenario 2, manufacture’s profit increases with both \( \sigma \) and \( \tau \); higher uncertainty leads to larger orders from retailers without imposing any holding costs on the manufacturer. Thus manufacturer has incentive to deliberately lead retailers into thinking that the demand is more uncertain then it actually is.

The channel profit is highest for Scenario 1, where all decisions are centralized and are based on a pooled forecast based on preliminary information from each market. The inventory levels are decided by the manufacturer and the retailers act as pass through agents. For retailers, profit is also highest for Scenario 1. Thus the retailers would like to force the manufacturer to take all the risk and follow a vendor management inventory (VMI) approach. When retailers have to make inventory decisions, they will of course be better off with reduced uncertainty by having pooled forecast available to them before placing orders. (\( \hat{\varphi}^2 < \varphi^2 \) and therefore \( \Pi_r(2) < \Pi_c(3) \).) A shared forecast allows them to keep the same service level \( k' \) but at lower levels of inventory.

7. Conclusions

Normally we would expect that both manufacture and retailers benefit from the implementation of the information system. However, the benefits could be asymmetrical and channel members may have to agree on some sharing mechanism.

This work extends the work by Iyer and Bergen [12] and Kurtulus, Uklu, an Toktay [14] to the case of supply chains which have multiple retailers that can provide preliminary demand forecast that can then be used by the manufacture to support a VMI type supply chain solution or can be used to improve individual retailers forecasts before they place final order. However we find that a centralized decision making with forecast pooling leads to highest channel profit, but the manufacture, as the central decision maker is worse off because it ends up bearing all the inventory risks. The manufacturer will thus not have much incentive to implement it. This means that retailers will have to provide some additional incentives to the manufacturer to build such a system. Since this is a stylized model there is a need for more empirical work on how these mechanisms are actually working. More studies need to be done especially to analyze how and where benefits are being realized in the supply chain. There are a number of limitations to the model: (i) we have considered only single period model (ii) we have assumed that the retailers cannot collaborate with each other directly (iii) we have assumed the manufacturer does not operate a competing retail store (iv) we have not looked into the cost of adopting the information systems (v) we have not examined the contract mechanism(s) that would induce the adversely affected party to adopt an information sharing system (vi) we have not looked at possible power relationships in the supply chain. We plan to look at some of these issues in a future work.
8. References:


