# Simulation Study Of A Decision Focused Supply Chain Model

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**Abstract:** Effective supply chain management tends to become a pivotal issue in manufacturing competitiveness nowadays. The concept of seamless supply chain is emerging for encouraging the market place information to move through the supply chain as efficiently as possible with Information Technology as a key enabler. This offers immense opportunities that can best be exploited by a judicious re-engineering of the systems and processes along the supply chain. However the analysis, design and implementation costs are often quite significant. Thus before embarking upon IT investment one requires a closer understanding of the value of information and its role in the chain dynamics. At present most SMEs are cautious and prefer phased IT investment only. Every phase may result in a more frequent review of the end customer demand picture that a preceding stage in the chain is willing to share with its supplier. The success of such a chain depends on whether this results in an improved performance for each player in the chain as well as for the chain as a whole. One of the pivotal factors is the decision making of each player based on the available local information at the time of decision making. Typically an information delay is associated with the available information due to the review period involved in accessing the demand picture. Thus decision focused supply chain models can help demonstrate the value of the available information to the chain members.

This paper presents an n stage decision focused supply chain simulation model and highlights its key results along with its industry implications. Here each chain stage acts as a decision stage. Based on the local information of the order and the sampled information available from the immediate customer (i.e. the preceding stage) about the end customer demand, decisions at each stage are made. A concept of information cost associated with more frequent sampling of the end customer demand, is used as part of the total system cost. The key insights from our simulation study are quite interesting. A seemingly good decision at a stage based on local information often ends up as not only detrimental to the total chain costs but also to the total costs of the stage itself. This indicates that decision integration across the chain is a critical factor for ensuring success of the information enriched chain. The impact of increased IT investment at all chain stages does not guarantee improvements. Sometimes phased IT investment by a stage may be counter-productive. Thus a careful analysis of the chain with a focus on integrated decisions is useful to ensure success. There is a need to evolve a judicious use of decisional flexibility at selected chain stages.

**Keywords:** Supply Chain, Simulation, Review Period, Decision-Information Synchronization Delay, Flexibility.

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## 1. Introduction

Time based competition is fast emerging as a key challenge to the manufacturing industry. One of the important problems faced by the manufacturing managers is the lack of proper visibility to the end customer demands. This is due to the manner in which the distribution chains linking the manufacturer to the end customers operate today. Typically the chain comprises many autonomous entities such as the retailer (who is in direct touch with the end customer demand), a distributor (who obtains and meets the demands from the retailer), a regional centre (which is in direct contact with the distributor as a customer) and a manufacturer (who obtains the order information from the regional centre as his immediate customer). Each autonomous entity is involved in its own decision making on the magnitude and timing of the orders that are placed on their immediate suppliers based on the orders from their immediate customers. This is based on the available information from their immediate customers, which is often treated as a reflection of the end customer demand. However due to different lead times, business risks and opportunities taken by the chain entities, the autonomous decision making of each entity may turn to be counter-productive.

The manufacturers have started realize that the dynamic end customer demand can be met most cost -effectively only by a deeper appreciation of the chain dynamics. In our opinion there is a growing need for decision focused supply chain models that portray the key insights into the value of information in the context of the chain dynamics.

One of the key attributes of a successful winner in today's highly competitive market place is the ability to respond rapidly to the end consumer demand. To maximize competitive advantage all members within the supply chain should "seamlessly" work together to serve the end consumer [Towill, 1996]. A lot of re-thinking towards industrial relationships has, therefore, been necessary to move towards the seamless supply chain in which the "players" think and act as one. The main idea underlying partnership sourcing is that via closer ties and the resulting information sharing the partners will be more able to effectively meet their customers' demands. It is very easy to discuss the principles of partnership but the actual "how" of using the exchanged information to maximize benefits of all players has not been fully explored [Whiteoak, 1994].

Worldwide the industry is focusing on integrating the supply chains by exploiting the immense potential offered by Information Technology. In Indian industry the business environment and the internal structures are also being re-engineered to benefit from IT. For instance, apart from the direct orders from the immediate customers, the supply chain members are also aspiring to obtain the end customer demand picture from their immediate customers. However this is generally implemented in phases only. For instance one of the important limitations in integrating suppliers, manufacturers and customers is the lack of willingness to invest in total IT solutions that may link the entire chain to virtually share real -time information. Sometimes the mind set of the supply chain members also restricts the total IT solutions for the chain. Often phased IT implementations are made resulting in a partial increase in the visibility of the end customer demands at each phase. It is important to determine whether all such increases in visibility of the demand picture are really useful or not. In this environment there is a need for tools that help analyse the impact of various decisions based on the actual orders along with the reviewed demand information obtained from the immediate customers.

This paper aims to highlight the important aspects of integrated decision making in a chain by developing a simple demonstrative computer simulator that models an n stage decision focused supply chain. The performance of a distribution channel under various scenarios is studied, to get a deeper insight into the impact of various decision changes on the performance of individual members and also on the chain as a total system. The decisions relate to the flow of material from a subsequent stage (i.e. towards the manufacturer) based on the order information received from the preceding stage (from the end customer of the chain). The demand information is sampled by each stage for its use or for passing it to a next stage in the chain. The scheduling of the material flow decisions is based on whether stocks are available to fulfil a given order. The impact of the sampled information is cumulative along the chain and is ultimately faced by the manufacturer who has to continuously respond to sudden changes in requirement for its production. Since at each stage the decision making is based on the local information available at the time of decision making, there is always a possibility of erroneous decision making. Typically the more the review period exercised for the collection of information from the preceding stage, the more the likelihood of a poor decision at a given stage. It is important to model the role of information as an important entity within the system.

## 2. Background and Motivation

In this paper we are motivated to study the supply chains from a decision focused perspective where each decision maker in the chain has a defined level of flexibility. This flexibility allows him to individually decide what to order from its immediate supplier. The decision is based on the available information about immediate orders, available stocks and the end customer demands. The latter is collected using a review period policy from the preceding stage in the chain. The motivation for studying this chain has resulted from our background research on the judicious use of flexibility in manufacturing systems. This is now summarized to highlight our motivations to extend the concepts to the domain of supply chains as well.

Wadhwa (1988) suggested an explicit modelling of all entity (material, resource and information, etc.) flows in the context of manufacturing systems with a focus on decision points. For instance in flexible systems, the decision points guide the control on flow of the entities in the interacting processes [Wadhwa and Browne, 1990]. The system designers must design systems where the interacting processes, involving both the physical and the information entities, are so synchronized that there are minimal delays. In this context the delays may be associated with all entities such as material delay, resource delay and information delay, etc. It is important to visualize these delays and their impact in relation to the decision points that are managing the interacting processes. For instance in a review period based information monitoring policy, the decision points may work under the information delays [Wadhwa et al, 1997], and/or the decision delays [Wadhwa and Bhagwat, 1998a]. Further Wadhwa and Bhagwat (1998b) discuss the issue of Decision-Information Synchronization (DIS) delays in the context of various entity flows within the Semi-Computerized Flexible Manufacturing (SCFM) systems. These studies are indicating the need to focus on the value of recent information, while attempting to decide on a favourable review period policy. Based on these experiences we are motivated in studying the impact of DIS delays caused by review periods within the supply chain contexts. Here typically the end customer demand picture is accessed to from its preceding stage using a review period agreed on between the two adjacent chain stages along the chain.

We visualize a supply chain undergoing a phased IT implementation as an SCFM chain. Each stage of this chain has a decision maker who possesses flexibility to decide what to order from its supplier based on the customer demand picture available to him. An important issue in such an SCFM chain is the level of flexibility that should be available with the decision maker. Another interesting issue relates to the impact of the reduction of DIS delays (by reducing the review periods) on the performance of the supply chain, at any given level of flexibility. Industry will also be motivated to know how the chain costs, as a whole, are affected by the decisions of a particular member. For instance if a member tries to use its flexibility to optimize his individual performance, is it then always useful to him and/or to the chain ? In our opinion it may be expedient to study the supply chains from the flexibility perspective to draw out some basic lessons towards a judicious use of decisional flexibility at each stage in the chain. Now the industry mindset finds it difficult to believe that what appears to be their internal decision can be significantly counter-productive to the chain and through the chain dynamics they can result in your own performance loss. For discrete part manufacturing systems where the decisions are by design invoked at discrete points in time, it may be a very important mind set to change. Without this change, phased developments towards supply chains may bring about many unpleasant surprises. One of the culprits is the lack of valuable information about the end customer demand. In most real systems, there is a cost associated with obtaining more frequent and/or most recent information. This forms our primary motivation in developing and studying a decision focused supply chain model, which considers information costs as part of the total system costs.

## 3. The Role of Information in Supply Chains

In most supply chains only the player closest to the end customer has the luxury of knowing the true demand. Market information notoriously suffers from delay and distortion as it moves through the supply chain. The main issue in supply chain (re)design is to limit order magnification as the information moves up the supply chain (i.e. retaining information value). Jones and Towill (1997) presented research results aimed at analysing the "how" of information usage through the supply chain in order to take strategic advantage of the product delivery process (PDP).

The advantages of changing from traditional adversarial approaches to modern industrial relationships, such as partnership sourcing, have been well -documented by MacBeth and Ferguson (1994). In a seminal publication, Stalk and Hout (1990) emphasized the importance of time compression through a supply chain in order to get shorter lead times, order control, and stock level reductions. One available resource within companies, that invariably has an unnecessarily long lead time is demand information. In fact, Stalk and Hout (1990) specifically warn of the dangers of slow information lead times, summing up the problems with information delays when they state: "The underlying problem here is that once information ages, it loses value..... old data causes amplifications, delay and overhead.... The only way out of this disjointed supply system between companies is to compress information time so that the information circulating through the system is fresh and meaningful".

The major technology behind improved information flows was the advent of electronic data interchange (EDI). It offers greatly improved information flows and is an extremely important aspect within leading organizations in the fight to decrease lead times [Evans et al, 1993]. However, while the introduction of EDI in many companies has offered market improvement in the speed of transmission of orders (once sanctioned), the current information remains, not the least because the many decision processes which still remain block rapid data transfer to where they are really needed. In particular, there is still much untapped mileage in seeking to improve the order fulfilment processes from utilizing undistorted points of sale information. Information flow does not have the same lead time constraints as a production process has, and via IT it is possible to eliminate the information transmission lead time from one end of the chain to the other. The main constraint to enriching a supply chain with market sales data is the common attitude to the fact that information is power. As a consequence of the traditional culture, companies will deliberately distort order information to mask their intent not only to competitors but even to their own suppliers and customers, unbelievable though this may seem [Towill, 1996]. In contrast, Ackere et al (1993) argued that managers could and should redesign their business processes to gain competitive advantage and include an improved information flow in their new strategy. They offer some preliminary simulation results based on the MIT beer game, which show the tremendous potential which may be realized by redesigning the handling and usage of market sales information throughout the supply chain.

The importance of measuring the value of information to exploit it to its best strategic advantage has been strongly advocated by Glazer (1993). Glazer states that although through the implementation of IT many companies are swimming with information, very few have gained a competitive advantage via their improved dataflow. Implementation of IT is not enough if it only transfers the previous data pool faster; management of the information itself is the key variable. Generally in most of the supply chains, the end consumer demand is converted to order information and passed down through the supply chain to trigger product release to the customer. In the traditional supply chain each "player" receives an order from its immediate customer, from which a decision on the required internal order rate to satisfy its stock targets (which may be Zero) is made. The decision process normally involves a certain amount of "hunch" judgement to forecast what is happening within the market place so as to try to make the company stay in control of the situation. Transferring information through a supply chain in a traditional "blind" manner gives rise to the "law of industrial dynamics" as originally stated by Burbidge (1989): "If demand for products is transmitted along a series of inventories using stock control ordering, then the demand variation will increase with each transfer". In practice both the bias and the noise distorting the demand information through its transfer between echelons lead to a vast stock holding in the chain in a desperate bid to eliminate customer service problems. Not only does stock holding across the chain cost money to maintain, but if carried to excess it also results in write-off due to obsolescence. This amplification phenomenon has been widely researched and simulated to enable opportunities for good supply chain design. The general consensus is that in the real world if there is a situation in which the demand might amplify, then it will certainly do [Towill, 1992]. So, the farther away from the consumer an echelon is within the supply chain, the less it is aware of the true consumer demand. Hence, as Forrester (1960) pointed out, it is the more likely that such an upstream "player" will completely misread the market with disastrous effects on profitability. This is a far cry from the usual supplier-retailer relationship where the retailer determines how much stock it will order from the supplier with both parties double guessing the true state of the system [Towill, 1994].

Now let us focus on the decisional flexibility of each decision making member of the chain. The beer game is representative of a four level supply chain and clearly shows the severe difficulties experienced by independent decision makers when matching the product flow to consumer's demand. The game and its environment, which are described in detail by Sterman (1989) and Senge (1990), basically involve several teams of four "players" mimicking a supply chain incorporating retailer, distributor, warehouse and factory. The objective is to minimize cumulative costs over the length of the game due to excess inventory and stock outs. The retailer receives an order directly from the market and delivers beer accordingly from which he makes a decision on what to order from his distributor. From this order the distributor then decides what to order from the warehouse and so on. Each player tries to anticipate demand and balance inventory. However, due to the lead time of information transfer and subsequent product delivery, the task is not as easy as it first seems and consequently experienced decision makers often perform badly. From their experience, Sterman (1989) and Senge (1990) found that in the debriefing session which allows the playing of every beer game, the upstream players become completely disoriented concerning the market place demand. Indeed many of these players refuse to accept that so much confusion could result from a simple step change in demand and are adamant that the real cause of their chaotic decision making is the volatile market place.

placed to upstream level only at the end of a day. The order placed by a downstream member shall reach the immediate upstream member immediately. However, even if the upstream member is capable of fulfilling the order received from downstream immediately and the transit time is zero , the replenishment stock shall reach the downstream level by to-morrow morning. A schema indicating the various decisional stages is shown in Figure 1.

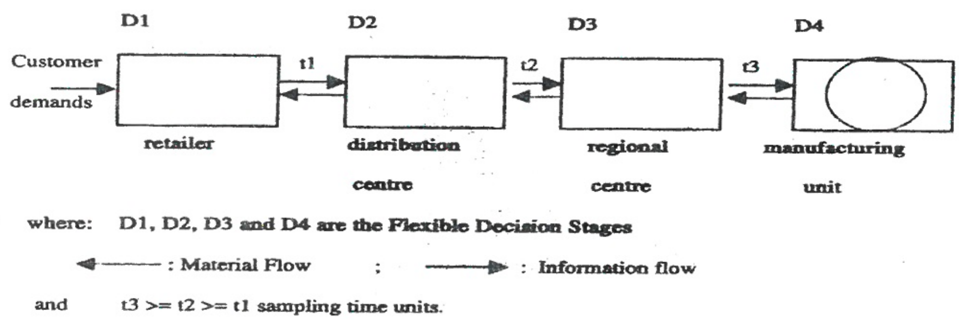



**Figure 1. Schematic Presentation of the Decisional Stages of A Typical Supply Chain where Each Stage Orders Material From Its Dedicated Supplier**

The beer game does not offer the possibility of reviewing the end customer demand picture at various decisional stages. In practice each decision stage has generally the possibility of accessing the end customer demand picture from its preceding stage during a mutually acceptable review period. We are therefore motivated to study such a decision focused supply chain in this paper.

## 4. Decision Focused SCM Model

In this paper, a four level multi-echelon physical distribution system has been modeled as a decision focused supply chain model. The different levels from bottom-up are customer, retailer, distribution centre, regional centre and manufacturing unit. The end product demand at the retailer level is independent, irregular and uncertain. Each level maintains an inventory level to meet the unexpected demands from downstream members. Replenishment orders are placed whenever the inventory position falls below the minimum predetermined quantity. The inventory position equals the inventory on hand plus outstanding orders minus backorders. The transit time between any two levels is known and constant. Stock outs if any, are backordered. A penalty cost is incurred for each backorder occurrence. The inventory level can be reviewed and accordingly an order can be

Since the demand for end products arrives at retailer level, the distribution centre samples demand data after say t1 time units from the retailer. The distribution centre (D.C.) thus receives a certain demand pattern after joining the latest data with the previous data on a graph. Similarly, the regional centre (R.C.) samples demand data every t2 time units from the D.C. The D.C. conveys the estimated demand to the R.C. if the exact demand status is unknown to it. Further, the manufacturing unit (M.U.) samples demand data from the R.C. after every t3 time units. This way the M.U. gets an estimated demand pattern. Based on this demand information the M.U. plans and schedules its production for the next sampling period, i.e. t3 time units till the latest demand data are received. Any excess or shortage of finished goods inventory after fulfilling an order from downstream at the manufacturing unit level, is adjusted to the production schedule of the next sampling period. This is done by not producing an excess quantity during the next period (for a maximum number of days till a new demand arrives) in case of excess inventory, and by producing extra products than scheduled in the next period (for a maximum number of days till a new demand arrives) in case of shortages. The production capacity of the M.U. is limited to a certain maximum predetermined level.

The expected total system cost is determined, which includes holding cost, ordering cost, shortage cost, transportation cost and information cost at all levels of the supply chain. The following parameters are collected in order to estimate the costs at each level and the total system costs.

1. Average ending inventory at each level
2. Number of days shortages occurred and in what quantities at each level
3. Number of replenishment orders placed at each level
4. Number of times demand information is collected at different levels
5. Number of dispatches made at various levels

## 5. Decision Logic At Each Stage

Discrete event simulation models were developed for a typical decision focused supply chain scenario. The decision logic incorporated for the retailer, the distributor and the regional centre was similar. Decision makers at each of these stages had the flexibility of deciding the safety stock levels and the re-order quantities to work under the popular (S, s) policy. The overall decision logic to deal with stocking, ordering and shortages is summarized in the flow chart shown in Figure 2. Similarly, Figure 3 summarizes the decision logic of the manufacturer as a distinct decision stage. Its distinctiveness stems from the fact that it has a capacity limit that determines the maximum it can produce over a given period. The decision maker exercises his flexibility to determine the level of production in a given scenario.

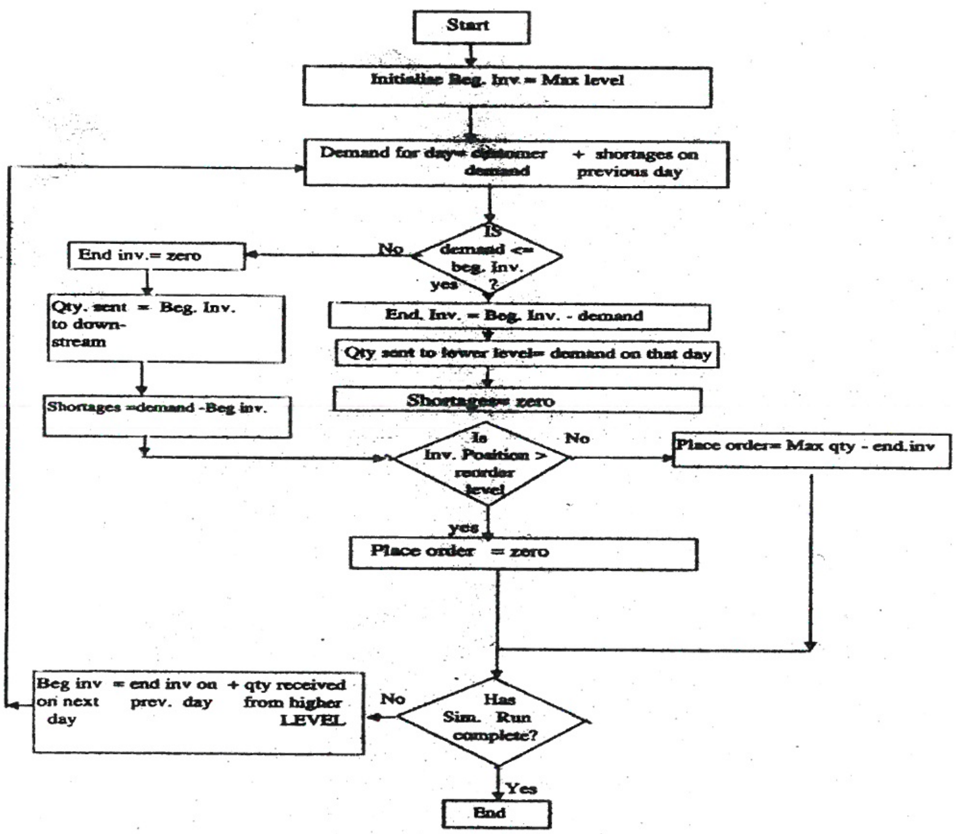



**Figure 2. Flow Chart Showing the Decision Logic at the Retailer, Distributor, Regional Centre**

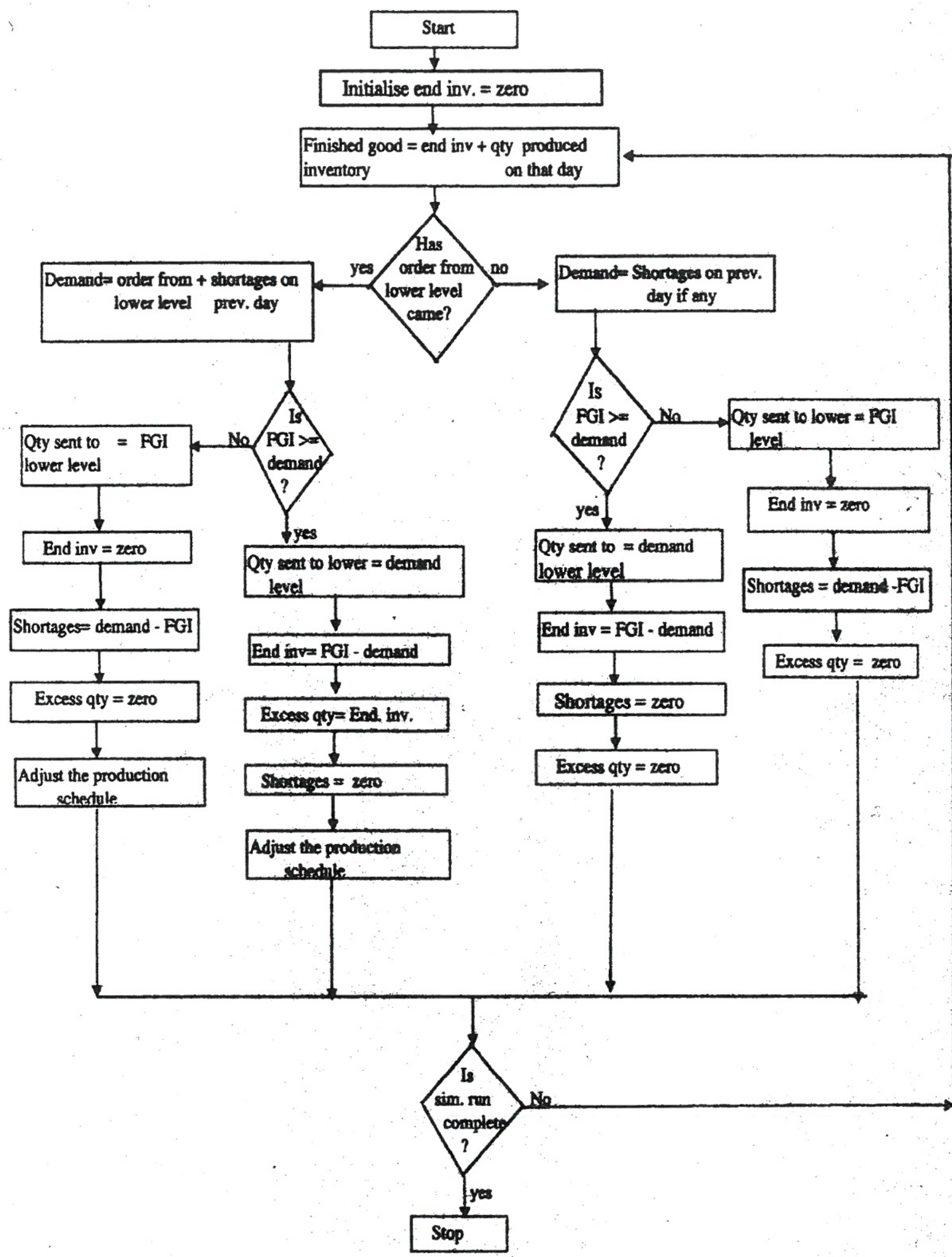


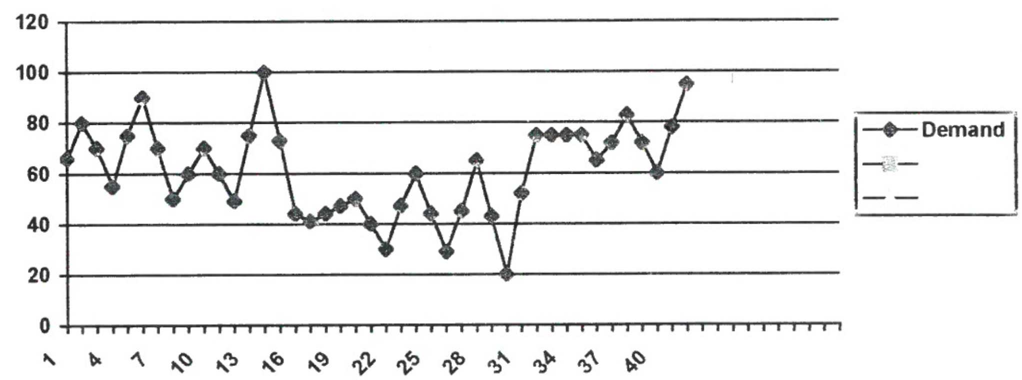

**Figure 3. Flow Chart Showing the Decision Logic at the Manufacturing Unit**

## 6. The Impact of Review Period Policy

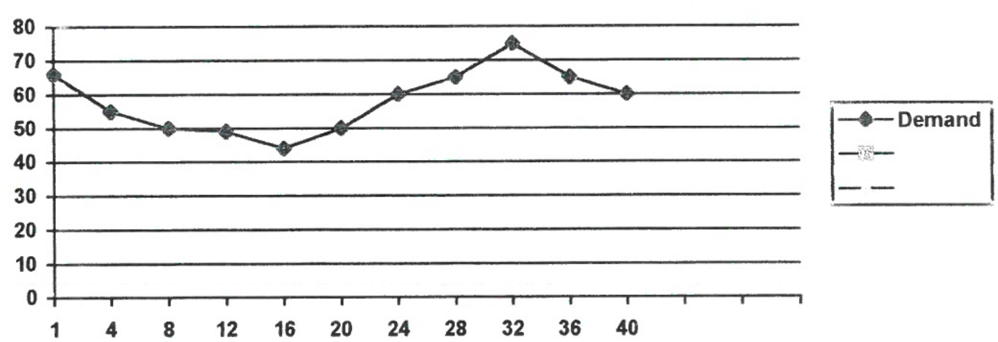
A review period based policy is used at each stage in the chain to acquire the end customer demand picture from its preceding stage. Only the retailer gets the actual customer demand picture. In order to visualize the impact of this simple and intuitive policy used by most supply chains in Industry, we have developed the following graphs where the $x$ axis shows the number of time units (say days) and the $y$ axis represents the demand quantities.

manufacturing unit samples information after every 8 time units from the regional centre and the demand picture which it gets from sampled information across the supply chain is shown in Graph D. It is quite clear that there is a significant difference between the actual demand pattern as shown in Graph A and the demand pattern which is received by the manufacturing unit shown in Graph D. This may adversally affect the performance of the chain (extended enterprise) with the customer demands not met in time or may be the enterprise ends up producing or stocking excess products.

**GRAPH A. Actual and customer demand experienced by Retailer**




**GRAPH B. End customer demand picture reviewed after every 4 days by the Distributor**

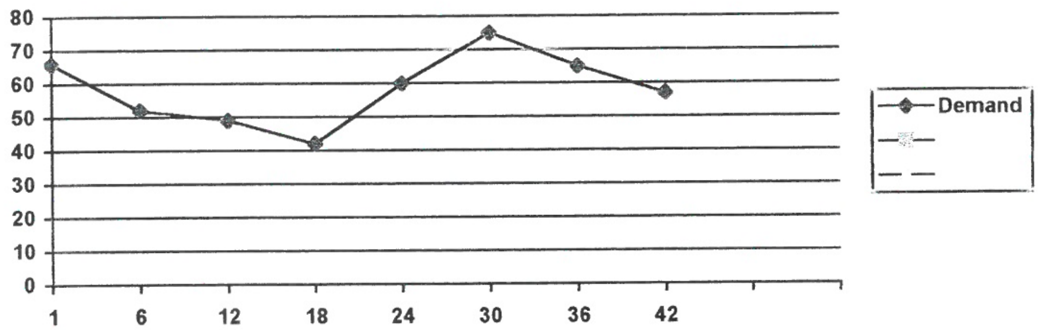



Graph A shows the actual customer demands at the retailer level over a period of time. Since the distributor samples information after every 4 time units he tends to get distorted demand information as it is obvious from Graph B which shows the demand pattern as received by a distributor. Now the regional centre reviews information after every 6 time units from the distributor. Graph C shows the demand pattern received by the regional centre. Finally, the

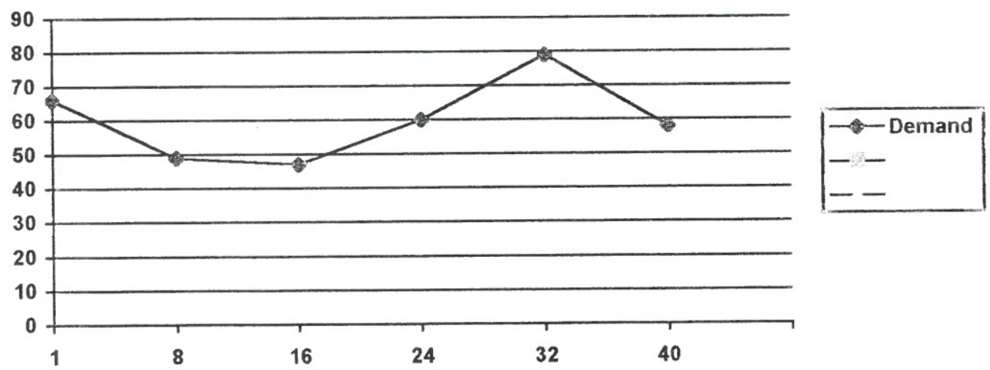
Similarly let us visualize another review period policy on this chain which is characterized by a different frequency of sampling information at each stage.

Graph E again shows the customer demands at the retailer level over a period of time. For the case when D.C. samples after every 3 time units with R.C. sampling after every 5 time units and

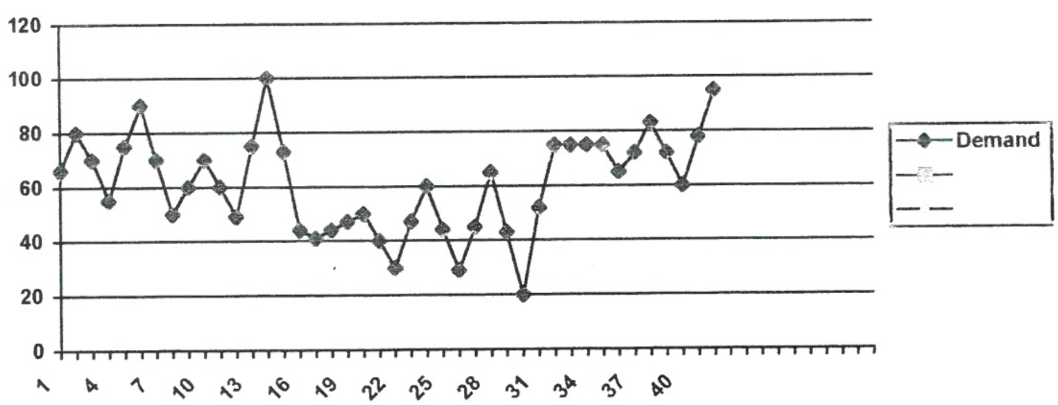
**GRAPH C. End customer demand picture perceived by RC using 6 day review**




**GRAPH D. A (4-6-8) review period based demand picture for the manufacturer**

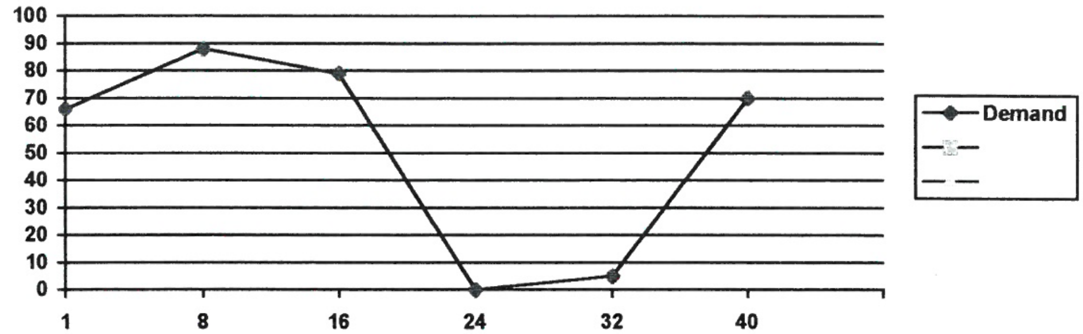



**GRAPH E. Actual demand picture at the retailer**

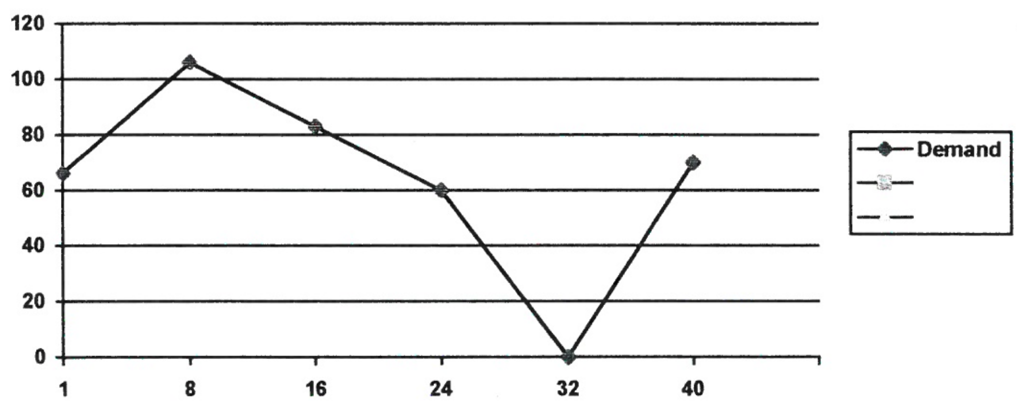



M.U. every 8 time units; the demand pattern as received by the M.U. is shown in Graph F, i.e. for the case of (3-5-8) sampling. Note that this is entirely different from Graph D, i.e. the demand pattern received by M.U. in case of (4-6-8) sampling. Thus it is clear that different review periods at various levels also cause the information distortion. Graph G shows the demand pattern received by M.U. when there are only 3 levels in the supply chain, i.e. when D.C. samples from the retailer every 3 time units, and M.U. samples from D.C. every 8 time units i.e. the (3-8) case. Next, Graph H shows the demand pattern received by M.U. when there are only 3 levels in the chain but for the

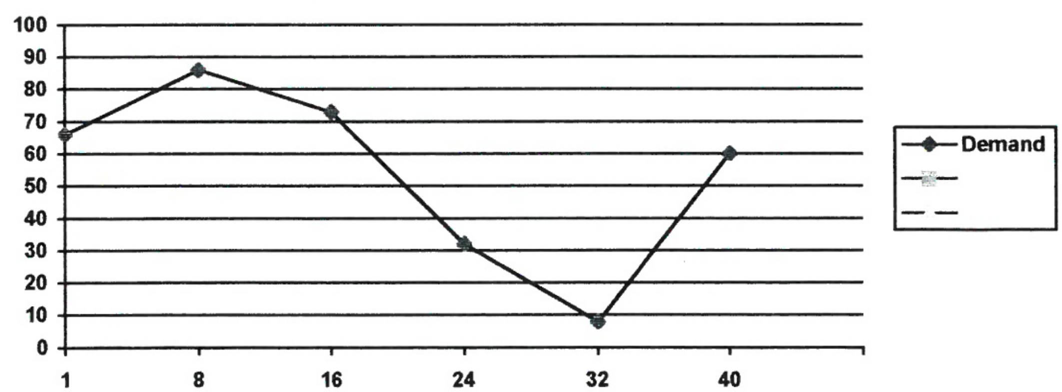
**GRAPH F. A (3-5-8) review period : Perceived demand picture at the manufacturer**




**GRAPH G. A (3-8) review period for a 3 level supply chain : Manufacturers Perception**




**GRAPH H. A (5-8) review period for a 3 level chain : Manufacturers Perception**



(5-8) case. The distortion in the actual information is clearly visible in these cases. The notion of DIS delays described by Wadhwa and Bhagwat (1998) tends to capture the impact of such information distortions faced by various decision makers in a system. Typically the higher the review periods the higher will be the DIS delays and the greater the likely losses. In the case of supply chains, this is further worsened since various decisional stages need to sequentially deal with the DIS delays. Compared to the SCFM systems early proposed by Wadhwa and Bhagwat (1998), the SCFM chain is likely to make greater challenges to the researchers.

## 7. Simulation Results

In order to study the impact of alternative review period policies on the performance of the supply chain, a number of experiments was planned. The result of these experiments are now summarized and discussed. Each of the sample results were obtained from a simulation run of 42 days. Two rationing policies have been considered : one in which an order can be partially fulfilled if it exceeds the available stock, namely the split demand policy and the other in which an order cannot be split, namely the unsplit demand policy. The results are summarized in Table 1.

The cost parameters were taken as follows:

1) carrying cost = Rs. 0.5 /unit/day , 2) ordering cost = Rs. 60 /order ,

3) shortage cost = Rs. 5 /unit/day , 4) information cost = Rs. 50 /review and

5) transportation cost = Rs. 20/trip .

The effect of information review periods on the total systems cost can be visualized by comparing case 1 with casw 2 and case 8 with case 9. The higher cost in the 2$^{nd}$ as compared to the 1$^{st}$ case and in the 8$^{th}$ as compared to the 9$^{th}$ case is due to a distortion in the demand pattern caused by the discrete information sampling character of the review period policy. However note that in case 1 vs case 2, a decrease in the review period has resulted in a performance loss in terms of the total system cost. In practice this may have resulted in counter-productive results for the distributor and the regional centre. The distributor may have to pay more in order to obtain more frequent information from the retailer as it is typically the case. This may have been an incremental IT investment leading to more frequent information access as per a mutually acceptable review period with the retailer. So case 1 and case 2 reflect the counter-productive aspects of incremental IT usage between the two decision stages in our chain. On the other hand, case 8 and case 9 reflect the benefit of the review period reduction by the manufacturer in a 3 level chain. Note that despite an increased information cost, the total cost in case 9 is significantly economical than in case 8. This supplements our view that judicious investment in IT in a chain should be guided by an improved insight of the chain dynamics. Similarly the effect of transit time on the systems cost can be seen by comparing case 1 and case 3. The higher cost in the 3$^{rd}$ case is due to the increased transit time. It is clear that if IT can help reduce the transit time (by faster order processing and order placing) then this may also result in benefits.

The effect of the decision flexibility (on choosing the safety stock levels) at the alternative decision stages of the supply chain can be visualized by comparing cases 5, 6 and 7 with case 1. It is clear that such decisions in a supply chain can have a significant impact on the total systems costs. Further focusing our attention on cases 5, 6 and 7 indicates another interesting result. Use of decision flexibility at the retailer stage in this chain is more beneficial. A small change in stock level option by the retailer results in a significant reduction of the total system costs. Note that the changes required at the distribution centre (case 5) and the regional centre (case 7) are quite high. The impact of the number of levels on the total systems cost can be seen by comparing cases 2, 8 and 11. Of the three, case 2 has the highest cost involved due to the four levels of the supply chain. Case 8 has three levels, while case 11 has only two levels of supply chain and therefore case 11 has the least total systems cost involved with it. The effect of the two types of rationing policies on the systems cost can be noticed by comparing case 1 and case 4. Case 9 and case 10 differ only in that the manufacturing unit in case 10 samples information directly from the retailer instead of sampling it from the distribution centre as in case 9. Therefore information received by the manufacturing unit in case 10 is more reliable and true and, as such, it has a comparatively lower total systems cost associated with it. This shows how IT can decrease the systems cost in an effective manner provided it is reviewed directly by the retailer.

**Table 1. Summarizing the results obtained under alternative review period based information sampling used at different decision stages in the supply chain model**

| Serial no. | Sampling time interval | Retailer (s, S) | Dist. Centre (s, S) | Regional Centre (s, S) | Rationing policy | Transit Time (Days) | Expected Total System's Costing Rs. |
|---|---|---|---|---|---|---|---|
| *1.* | *4- 6- 8* | *(60,150)* | *(125,300)* | *(200,500)* | *Split demand* | *zero* | *23,383.80* |
| 2. | 3- 5- 8 | (60,150) | (125,300) | (200,500) | Split demand | zero | 26,243.80 |
| 3. | 4- 6- 8 | (60,150) | (125,300) | (200,500) | Split demand | one | 25,155.50 |
| 4. | 4- 6- 8 | (60,150) | (125,300) | (200,500) | Unsplit demand | zero | 24,733.00 |
| 5. | 4- 6- 8 | (60,150) | (200,300) | (200,500) | Split demand | zero | 23,378.00 |
| 6. | 4- 6- 8 | (80,150) | (125,300) | (200,500) | Split demand | zero | 22,558.50 |
| 7. | 4- 6- 8 | (60,150) | (125,300) | (300,500) | Split demand | zero | 22,272.30 |
| 8. | 3- 8 | (60,150) | (125,300) | N. A. | Split demand | zero | 17,095.30 |
| 9. | 3- 5 | (60,150) | (125,300) | N. A. | Split demand | zero | 15,614.80 |
| 10. | 3- 5 * | (60,150) | (125,300) | N. A. | Split demand | zero | 15,094.30 |
| 11. | 5 | (60,150) | N. A. | N. A. | Split demand | zero | 9,424.50 |

* In this case both the distribution centre and the manufacturing unit are sampling information from the retailer after 3 and 5 time intervals respectively.

## Conclusions

It is useful to develop decision focused supply chain models for studying the semi-computerized flexible manufacturing chains operating under the review period policy. The role of the review period policy is to access the end customer demand picture from the preceding stage in the chain. This paper develops simulation models of a four- stage supply chain in order to study the role of review periods and the use of decisional flexibility at each stage of the chain. This chain represents a general scenario under which many manufacturing companies typically operate. Phased IT implementations in these systems generally aim to decrease the review periods and to increase the decisional flexibility. In practice these increments are initiated at the individual stages for their local implementations (i.e. with their immediate customers). Our research efforts indicate that these increments need to be carefully decided and implemented as sometimes these may become counter-productive due to the chain dynamics. The key insights indicate that the review periods adversally impact on the total system costs of the chains. However not all IT investment locally exercised at individual stages, to reduce the review periods, can yield benefits. Some may result in an increase of the total costs rather than in a decrease of the costs. It is seen that due to the decision-information synchronization delays [Wadhwa and Bhagwat, 1998], the chains with a smaller number of chain stages are likely to be superior in performance. Finally the use of decisional flexibility at each stage has different impacts on the chain performance. For instance in our simulation models, small changes in the safety stock levels at the retailer have been considered to be more cost-effective if compared to the large increases in the safety stocks at the regional centre. In our opinion there is a growing need for developing decision focused supply chain models to help change the mindsets of the chain players towards a more effective integration of the supply chains.

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