PERFORMANCE OF SUPPLY CHAIN WHEN USING SELECTED COORDINATION MECHANISMS

A thesis

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Certificate

*This is to certify that the thesis entitled "**Performance of Supply Chain when using selected Coordination Mechanisms**" which is being submitted by **Ambilikumar C K** in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy, to the Cochin University of Science and Technology is a record of the bona-fide research work carried out by him under our supervision and guidance, in School of Engineering, Cochin University of Science and Technology, Cochin – 682 022 and no part of the work reported in this thesis has been presented for the award of any degree from any other institution.*

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Declaration

*I hereby declare that, the work presented in this thesis entitled "**Performance of Supply Chain when using selected Coordination Mechanisms**" is based on the original research work carried out by me, under the guidance and supervision of Dr. M. Bhasi (Guide), Professor, School of Management Studies and Dr. G. Madhu (Co-Guide), Professor, Division of Safety Engineering, School of Engineering, Cochin University of Science and Technology, Cochin – 682 022 and no part of the work reported in this thesis has been presented for the award of any degree from any other institution.*

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21/01/2015

ABSTRACT

Coordination among supply chain members is essential for better supply chain performance**.** An effective method to improve supply chain coordination is to implement proper coordination mechanisms. The primary objective of this research is to study the performance of a multi-level supply chain while using selected coordination mechanisms separately, and in combination, under lost sale and back order cases. The coordination mechanisms used in this study are price discount, delay in payment and different types of information sharing. Mathematical modelling and simulation modelling are used in this study to analyse the performance of the supply chain using these mechanisms.

Initially, a three level supply chain consisting of a supplier, a manufacturer and a retailer has been used to study the combined effect of price discount and delay in payment on the performance (profit) of supply chain using mathematical modelling. This study showed that implementation of individual mechanisms improves the performance of the supply chain compared to 'no coordination'. When more than one mechanism is used in combination, performance in most cases further improved.

The three level supply chain considered in mathematical modelling was then extended to a three level network supply chain consisting of a four retailers, two wholesalers, and a manufacturer with an infinite part supplier. The performance of this network supply chain was analysed under both lost sale and backorder cases using simulation modelling with the same mechanisms: 'price discount and delay in payment' used in mathematical modelling. This study also showed that the performance of the supply chain is significantly improved while using combination of mechanisms as obtained earlier. In this study, it is found that the effect (increase in profit) of 'delay in payment' and combination of 'price discount' & 'delay in payment' on SC profit is relatively high in the case of lost sale. Sensitivity analysis showed that order cost of the retailer plays a major role in

the performance of the supply chain as it decides the order quantity of the other players in the supply chain in this study. Sensitivity analysis also showed that there is a proportional change in supply chain profit with change in rate of return of any player. In the case of price discount, elasticity of demand is an important factor to improve the performance of the supply chain. It is also found that the change in permissible delay in payment given by the seller to the buyer affects the SC profit more than the delay in payment availed by the buyer from the seller.

In continuation of the above, a study on the performance of a four level supply chain consisting of a manufacturer, a wholesaler, a distributor and a retailer with 'information sharing' as coordination mechanism, under lost sale and backorder cases, using a simulation game with live players has been conducted. In this study, best performance is obtained in the case of sharing 'demand and supply chain performance' compared to other seven types of information sharing including traditional method. This study also revealed that effect of information sharing on supply chain performance is relatively high in the case of lost sale than backorder. The in depth analysis in this part of the study showed that lack of information sharing need not always be resulting in bullwhip effect. Instead of bullwhip effect, lack of information sharing produced a huge hike in lost sales cost or backorder cost in this study which is also not favorable for the supply chain.

Overall analysis provided the extent of improvement in supply chain performance under different cases. Sensitivity analysis revealed useful insights about the decision variables of supply chain and it will be useful for the supply chain management practitioners to take appropriate decisions.

Keywords: Supply chain, Coordination, Lost sale, Backorder, Price discount, Delay in payment, Information sharing, Mathematical modelling, Simulation modelling, Sensitivity analysis, Profit/Cost.

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INTRODUCTION

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1.1 Back ground

A Supply Chain (SC) is a network of firms that produce, sell and deliver a product or service to a predetermined market segment (Chopra and Meindl, 2004). The SC includes suppliers, manufacturers, distributors, transporters, warehouses, all functions involved in fulfilling a customer request and customers themselves. Each stage of the SC performs different processes and interacts with other stages of the SC. Supply Chain Management (SCM) is one of the fastest growing and well appreciated management disciplines in the world. It consists of management of product flow, information flow, fund flow and services flow internal to an organization and between organizations to fulfill a customer requirement along with reasonable targeted profit. The parameters which show the need for SCM are: i) pervasiveness ii) interdependence iii) profitability and survival. Pervasiveness means every organization makes a product or provides a service that someone values or is used by some other organization. Most of the organizations function as part of an SC knowingly or unknowingly. It means that all these organizations are to be interdependent one way or the other. Profitability and survival indicates that all the organizations must carefully manage their operations to work together with other interrelated organizations for long term prosperity and survival. SCM philosophy includes the following: i) the entire SC is a single integrated entity, ii) the cost, quality and delivery requirements of customer are shared by every company in the chain and iii) inventory is the last resort for resolving supply and demand imbalance between the levels in the SC. The objective of an SC is to maximize the overall value generated. The value an SC generated is the difference between what a final product is worth to the customer and the effort the SC expends in filling the customer’s request (Chopra and Meindl, 2004). For most commercial SCs, Value will be strongly correlated with SC profitability, the difference between the revenue generated from the customer and the overall cost across the SC. However, the process of maximizing the SC profit is to be implemented by ensuring the satisfaction of customers as well as SC members without which the business will not run for long. One of the emerging trends in the SCM is the realization that long term strategic and operational partnerships among the players in the SC through combination of various appropriate coordination mechanisms are essential for improving the performance, responsiveness and also to achieve satisfaction among members of the SC. Supply Chain Coordination (SCC) among various departments of an organization and between organizations are essential to achieve these SC objectives. Achieving coordination is a big challenge for any SC as it may involve multiple firms with different policies, priorities and objectives. Coordination with in an SC is a strategic response to the problems that arise from inter-organizational dependencies within the chain and a coordination mechanism is a set of methods used to manage interdependencies between organizations (Xu and Beamon, 2006). The decision taken by any SC member will affect the performance of the other members and finally the SC. This shows the significance and necessity to study coordination in SC.

1.2 Evolution of Supply Chain Management

Figure 1.1 shows the evolution of SCM. During early 1900s, the business decisions were taken based on some thumb rules and there was no scientific approach to manage the business. At that time, it was successful to a certain extent as there was no competition at all and each firm was a monopoly in their area of operation. Afterwards, the uncertainty in demand and other operating parameters with an element of competition induced the researchers and practitioners to search for new methods and procedures to manage the unexpected situations. Thus, the lot sizing techniques were developed for continuous and independent demand items to decide on the optimal order quantity and the proper time at which order is to be placed. Accordingly, the concept of Material Requirement Planning (MRP) was introduced for determining the quantity and timing for the acquisition of dependent demand items needed to satisfy Master Production Schedule (MPS) requirements which give formal details of the production plan and converts this plan into specific material and capacity requirements. Then, the requirement of an element of coordination to synchronize all the aspects of business in an organisation was aroused. Manufacturing Resource Planning (MRP-II) system is then evolved to coordinate sales, purchasing, manufacturing, finance and engineering by adopting a focal production plan and by using one unified data base to plan and update the activities in all the systems. The evolution of IT created a revolution in the world of business. One of the reasons for this revolution is that with the support of IT, people developed a technique called Enterprise Resource Planning (ERP), an extremely powerful tool which provides seamless information system to support the various functional business modules of an enterprise. ERP package, if chosen correctly, implemented judiciously and used efficiently, will raise the productivity and profit of the companies dramatically (Telsang, 2005). To complete a business successfully, a number of activities and organizations are involved and people come to know that just with the improvement in an organization will not result in complete success for which coordination is required among all the organizations involved in fulfilling a customer request. Finally, the concept of 'Supply Chain' (SC) evolved to cater to the required coordination thereby improving the overall performance, avoiding individual optimization.

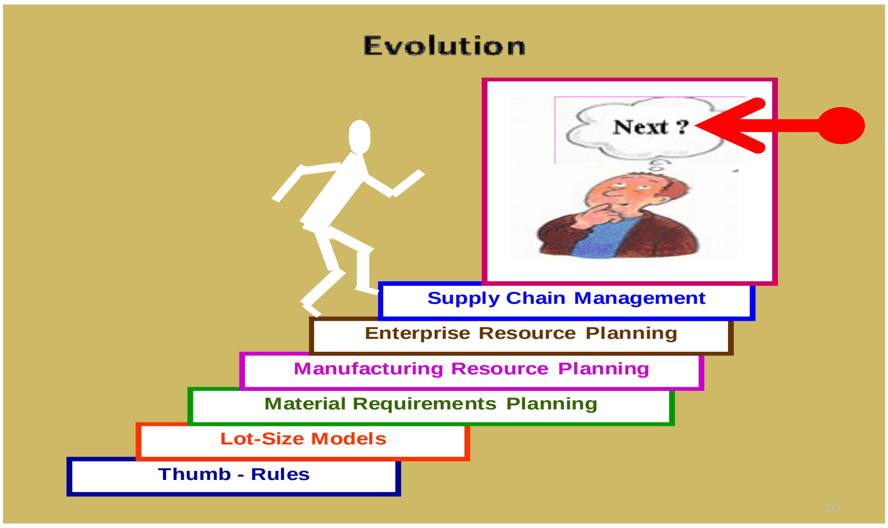

Figure 1.1: Evolution of supply chain management

1.3 Supply Chain

A supply chain is an integrated system consists of many independently managed organizations acting together for a common goal, with each organization dependent on the performance of the other organization in the system. Generally, supply chain consists of different functions: logistics, inventory, purchasing and procurement, distribution, forecasting, production planning, intra-and inter-organizational relationships and performance measures

(Arshinder et al., 2008). The term supply chain forms the picture of how organizations are linked together. Figure 1.2 shows an overview of SC which consists of three divisions; supply/inbound logistics, production, distribution/outbound logistics. In depth analysis shows that third party logistics, distributors and warehouses are also some of the important elements of SC. The information flow is bidirectional as the information from each stage of the SC is required everywhere in the system. Product flow is only in forward direction as no product will flow backward normally, except in the case of some special situations, such as buyback or service, etc. Money flow is in backward direction as payment is made by all upstream (e.g. retailer to wholesaler/distributor) players to its downstream players in an SC. Regarding service flow, its direction is forward as upstream stage always provide service to its downstream players and finally to customers.

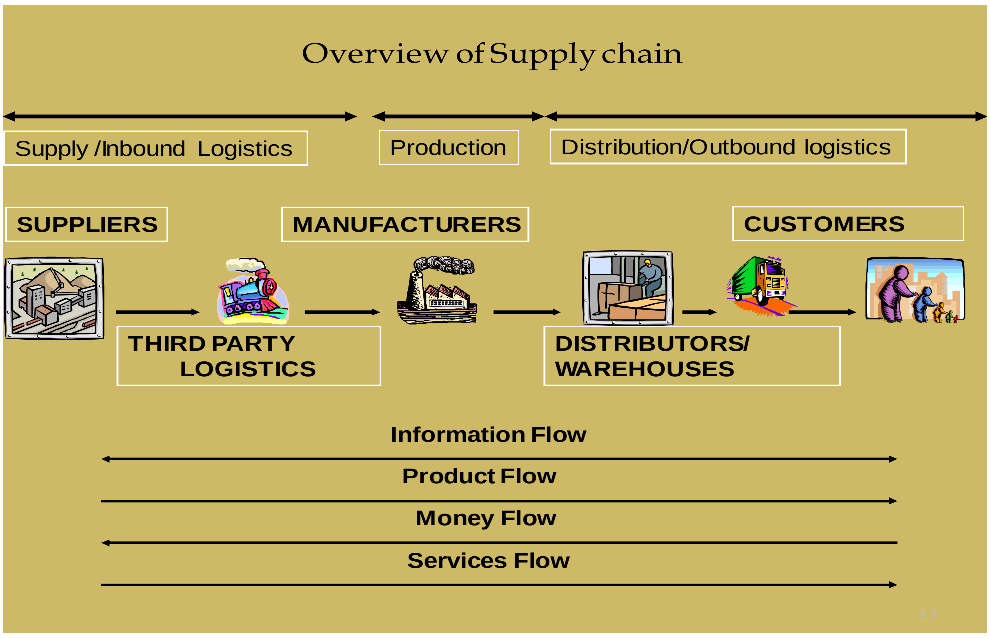

Figure 1.2: Overview of supply chain

Figure 1.3 shows the typical entities, objectives and overall concept of an SC. It also differentiates the whole SC into upstream and downstream players. It also provides the various parameters, such as product, price, store, quantity, customer, and time to be considered for achieving maximum profits. The mismatch between supply and demand is shown in the Figure 1.3. The aim is to match supply and demand profitably for products and services for which all the resources and facilities of SC should work jointly in all aspects.

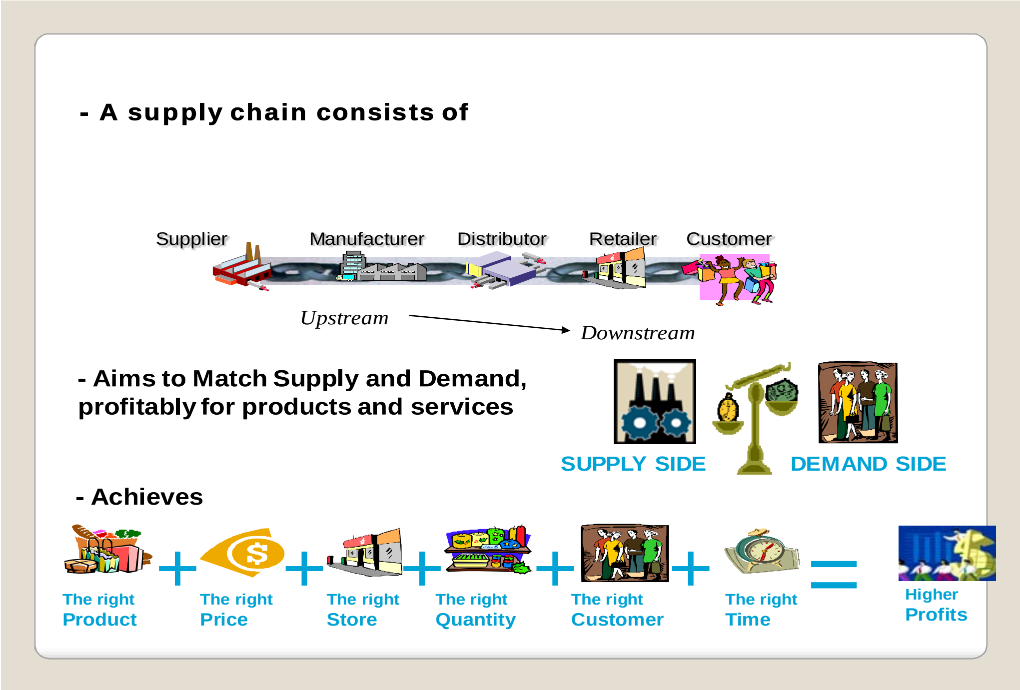

Figure 1.3: Concept of a supply chain

1.3.1 Structure of the Supply Chain

Figure 1.4 shows the typical structures of an SC. The first one is a dyadic SC which consists of only a buyer and a seller. Serial structure is one in which there will be only one firm at each level of SC. In the case of a convergent structure, there will be more than one firm existing at all levels except in the extreme right end of the SC where it has got only one player. Divergent structure is just opposite to that of the convergent SC as shown in Figure 1.4. Conjoined structure is one in which only one player will be in the middle (e.g. manufacturer) and more number of players will be there on both the sides. Network SC is the most general type and has got more than one player at every stage of the SC.

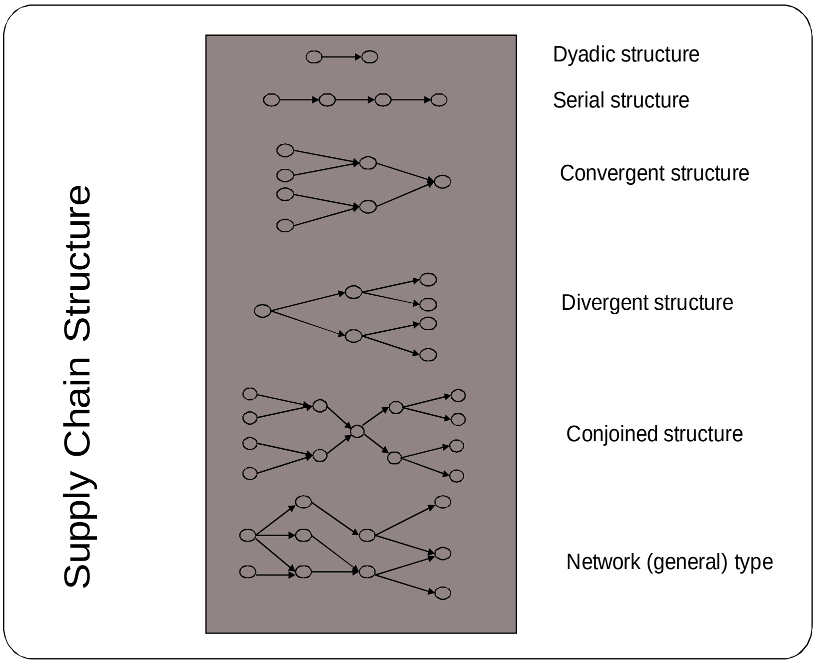

Figure 1.4: Typical structures of supply chain

1.3.2 Decision phases in a Supply Chain

The decision phases in an SC can be categorized in two ways based on i) the frequency of each decision and the time frame for which decision is taken and ii) its functions and they are shown in Figure 1.5

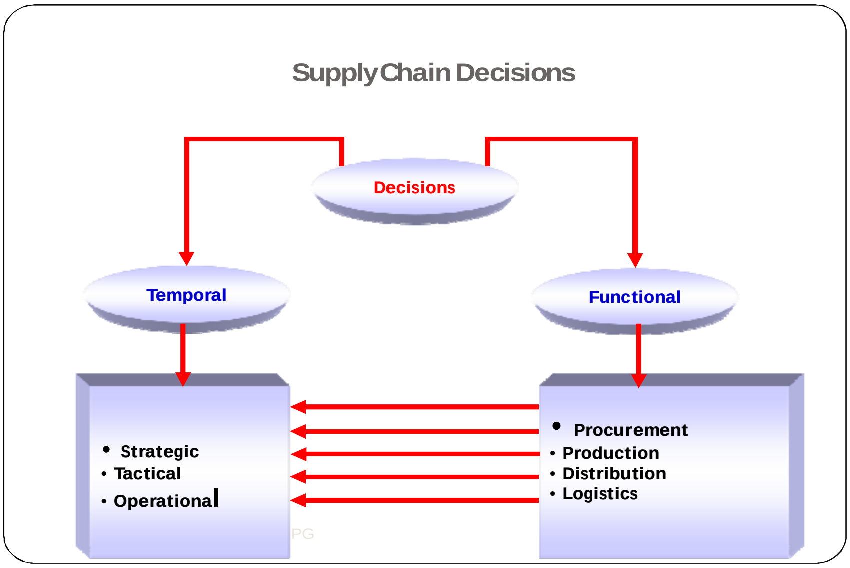

Figure 1.5: Supply chain decision phases

The first type categorization (temporal) of SC decision phases includes SC strategy or design, SC planning and SC operation respectively. During SC strategy or design phase, the details such as structure of SC, its configuration, resource allocation, the process each stage will perform and the period for which these details are designed are decided as per the requirement. These decisions are long term and expensive to alter immediately. So, the uncertainty in anticipated market conditions over the next few years is to be taken into account for deciding the details mentioned above. The SC planning phase includes decisions regarding which markets will be supplied from which locations, the subcontracting of manufacturing, the inventory policies and the timing and size of sales promotions. These decisions based on the first phase (SC design) define the set of operating policies that govern short term operations. The SC operation phase makes decisions regarding individual customer orders on daily or weekly basis based on the design and planning phase. The goal during this phase is to exploit the reduction of uncertainty and to optimize performance (Chopra and Meindl, 2004).

The second type of categorization (functional) includes procurement, production, distribution, and logistics. Procurement is concerned with a firm's total supply system (internal and external), supplier qualification and selection, optimal procurement policy, vendor managed inventories, and monitoring of continuous improvement in the SC. Production decisions include process design, capacity planning and scheduling, inventory management, manpower management, and quality of products. Distribution refers to the steps taken to move and store a product form the supplier stage to customer stage in the SC. Distribution network design based on the customer needs that are to be met and cost of meeting this customer needs is the major activity under this function. Logistics decisions consist of all activities related to warehousing and transportation throughout the SC.

1.3.3 Supply Chain: Process Views

An SC is a sequence of processes and flows that take place within and between different stages and combine to fill a customer need for a product. There are two different ways to view the process performed in an SC.

i. Cycle view: The process in an SC is divided into a series of cycles; each performed at the interface between two successive stages of an SC. Figure 1.6 shows the cycle view of an SC. Each cycle includes all processes directly involved in receiving and fulfilling the order from the downstream player. The cycle view of the SC is very useful when we consider operational decisions because it clearly specifies the roles and responsibilities of an SC. The detailed process description of an SC in the cycle view forces an SC designer to consider the infrastructure required to support these processes. (Chopra and Meindl, 2004).

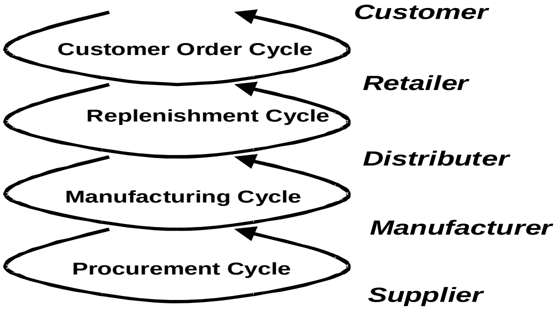

Figure 1.6: Cycle view of Supply chain (Chopra and Meindl, 2004)

ii. Push/Pull view: The processes in an SC are divided into two categories depending on whether they are executed in response to a customer order or in anticipation of customer orders. Pull processes are initiated with a customer order where as push processes are initiated and performed in anticipation of customer orders. All processes in an SC fall into one of these two categories depending on the timing of their execution relative to end customer demand. Figure 1.7 shows the push/pull process of an SC. A push/pull view of the SC is very useful when we consider strategic decisions relating to SC design. (Chopra and Meindl, 2004).

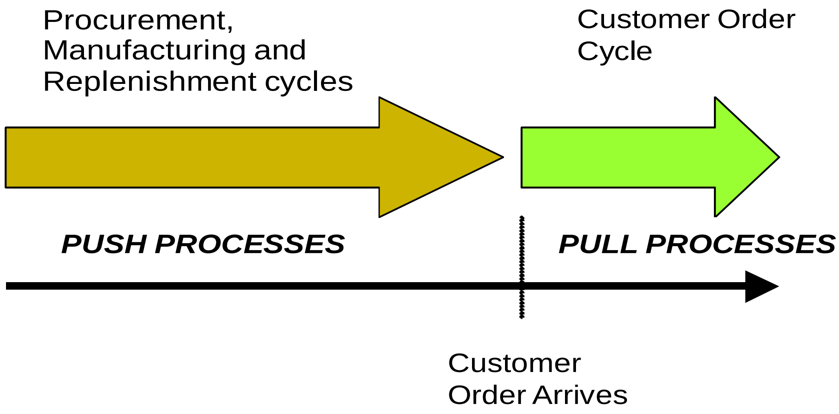

Figure 1.7: Push/Pull views of a supply chain (Chopra and Meindl, 2004)

1.3.4 Supply Chain: A Macro View

All supply chain processes in a firm can be classified into the following three macro processes and integration of these three macro processes is crucial for successful SCM

i) Customer Relationship Management (CRM): All processes that focus on the interface between the firms and its customers.

ii) Internal Supply Chain Management(ISCM): All processes that are internal to the firm

iii) Supplier Relationship Management (SRM): All processes that focus on the interface between the firms and their suppliers.

The above three macro processes manage the flow of information, product, funds, services required to generate, receive, and fulfill a customer request. (Chopra and Meindl, 2004).

1.3.5 Supply Chain Performance and Strategic Fit

A company's competitive strategy defines the set of customer needs that it seeks to satisfy through its products and services and the SC strategy is to create the required policies, resources and facilities to meet the competitive strategy. It means that SC strategy has to be designed based on competitive strategy. Strategic fit means that both the competitive and SC strategies have the same goal and it is very critical to a company's overall success. The tradeoff between efficiency and responsiveness of an SC is to be decided as per the nature of the business and customer needs and the SC is to be designed accordingly. Responsiveness is the ability to handle dynamic nature of the business. Efficiency means the ability to meet the customer requirement with minimum resources. In the present dynamic and competitive business environment, it is crucial that strategic fit should have agile intercompany scope. Agile intercompany scope refers to a firm's ability to achieve strategic fit while partnering with SC stages that change over time. The level of agility becomes more important as the competitive environment becomes more dynamic.

1.3.6 Supply Chain Performance Measures and Tools: A Classification

Performance measurement is generally defined as the process of quantifying the efficiency and effectiveness of action (Neely et al., 1995). Effectiveness is the extent to which customer's requirements are met, while efficiency measures how economically a firm's resources are utilized to achieve a predetermined level of customer satisfaction. Surveying the literature revealed that there are generally two classes of supply chain performance management (SCPM) systems: Financial (e.g., Traditional financial accounting, Activity Based Costing, and Economic Value Added approach) and Non-financial (e.g., Supply Chain Balanced Score Card, Supply Chain Operations Reference Model) (Agami et al., 2012). Financial performance measurement systems are generally referred to as traditional accounting methods for measuring supply chain performance. Logistic Scoreboard belongs to perspective-based measurement system (PBMS). The parameters that are used to measure the performance of supply chain can be classified based on following supply chain activities or operations (i) order plan (ii) sourcing, (iii) make/assemble, and (iv) delivery/customer (Gunasekaran, et al., 2004). For a detailed discussion of the above, refer Chapter 2 section 2.8

1.3.7 Supply Chain Drivers and Obstacles

A company can improve its performance in terms of responsiveness and efficiency by properly analysing and implementing four drivers of SC performance: facilities, inventory, transportation and information. These drivers not only determine the SC performance in terms of efficiency and responsiveness but also determine whether strategic fit is achieved across the SC. Once the SC strategy is made based on the competitive strategy, decision has to be taken on these four drivers based on the required level of responsiveness and efficiency for the existing SC structure.

The obstacles to achieve strategic fit are: i) increasing variety of products ii) decreasing product life cycle iii) increasingly demanding customers iv) fragmentation of SC ownership v) globalization vi) difficulty in executing new strategies. These obstacles are a very common phenomenon in the present business scenario. Overcoming these obstacles offers a tremendous opportunity for firms to use SCM to gain competitive advantage. This kind of situation necessitates combination of appropriate mechanisms and policies to achieve coordination between firms and to be an agile SC.

1.4 Matching Demand and Supply in a Supply Chain

The dynamic mismatch between demand and supply is big challenge for any SC where forecasting plays an important role. The forecast of demand forms the basis for all strategic and planning decisions in both an enterprise and an SC. Collaborative forecasting for an entire SC will be really a result oriented approach for decision making as it greatly increases the accuracy of forecasts and maximizes the SC performance.

Aggregate planning is a process by which a company determines levels of capacity, production, subcontracting, inventory, stock out, and even pricing over a specified time horizon. The role of aggregate planning is to meet the demand in such a way that it maximizes the profit. It is most important to perform aggregate planning under conditions where capacity is limited and lead times are long. Aggregate planning has a significant impact on SC performance and must be viewed as an activity that involves all SC partners.

The variation in demand over a time horizon has two components: predictable and unpredictable. Predictable variability is the change in demand that can be forecast. It can be managed using capacity, inventory, subcontracting, backlogs, short term price discounts and trade promotions. As far as supply is concerned, a firm can alter it by controlling a combination of production capacity and inventory.

1.5 Inventory Management in a Supply Chain

Inventory management is a planned approach of determining what to order, when to order, how much to order and how much to stock so that the cost associated with buying and storing are optimal without interrupting production and sales. The two major costs associated with inventory are ordering cost, and inventory carrying cost. Inventory carrying cost is the sum of holding cost (interest on capital) and storage cost (other costs such as rent, product deterioration and obsolescence, insurance etc).But in some cases, the term holding cost is only used to represent both holding cost and storage cost where storage cost may not have much importance. These two costs (inventory carrying cost and order cost) are opposing costs. So, the right quantity to be ordered is that strikes a balance between the two opposing costs. This quantity is referred to as Economic order quantity (EOQ). EOQ is that order quantity which minimizes the total cost i.e the sum of annual ordering and inventory carrying cost (Telsang, 2005).

Inventory exists in the SC because of mismatch between supply and demand. An important role that inventory plays in an SC is to increase the amount of demand that can be satisfied by getting products ready and available when the customer wants them. Another significant role inventory plays is to reduce cost by economies of scale that may exist during both production and distribution. Cycle inventory is the average amount of inventory used to satisfy demand between receipts of supplier shipments. The size of the cycle inventory is the result of the production or purchase of material in large lots. Companies produce or purchase in large lots to exploit economies of scale in the production, transportation, or purchasing process. So, decision on cycle inventory must be taken comparing the ordering cost and holding cost of the product. The key managerial levers for reducing lot size and thereby the cycle inventory in the SC without increasing cost are i) reduce the fixed ordering cost and transportation cost per order ii) implement volume based discounting schemes rather than individual lot size based discounting schemes iii) eliminate or reduce trade promotions and encourage everyday low pricing (ELDP) and base trade promotions on sell-through rather than sell-in to the retailer. Safety inventory is one that is held to meet the unexpected demand. The required level of safety inventory is lower in the case of continuous review policies than periodic review policies. The required level of safety inventory may be reduced and product availability may be improved if an SC can reduce demand variability, replenishment lead times and exploit aggregation. Seasonal inventory is one to meet the seasonal variations in demand.

One of the strategies for aggregate planning to improve the SC performance is the level strategy. Level strategy is one in which Inventories that are built up in anticipation of future demand or backlogs are carried over from high to low demand periods maintaining stable machine capacity and workforce levels with a constant output rate. Level strategy should be used when inventory holding and backlog costs are relatively low

1.6 Sourcing in a Supply Chain

Sourcing is the entire set of business processes required to purchase goods and services. It includes the selection of suppliers, design of supplier contracts, product design collaboration, and procurement of material and evaluation of supplier performance. Over the last decade, manufacturing firms have increased the fraction of purchased parts. Effective sourcing decisions thus have a significant impact on financial performance. Supply contracts, such as buy back, revenue sharing , quantity flexibility contracts, price discounts, two-part tariff & threshold contracts, revenue sharing, and design collaboration, improve the coordination and thereby the effectiveness of sourcing process. The following steps that can be taken to make the sourcing decisions effective in practice are: i) use the multifunctional teams to make result oriented strategy in all aspects ii) ensure appropriate coordination across regions and business units ii) always evaluate all the factors that influence the total cost of ownership and use for supplier selection iii) build long term relationship with key suppliers.

1.7 Transportation operations in a Supply Chain

Transportation refers to the movement of product from one location to another within the SC. The importance of transportation has grown with the increasing globalization in SCs as well as growth in e-commerce because both trends increase the distance product travel. Transportation decisions impact SC profitability and facility decisions within the SC. When designing transportation networks, shippers must consider the tradeoff between transportation cost, inventory cost, operating cost and customer responsiveness. The SC goal is to minimize the total cost while providing the desired level of responsiveness to customers.

1.8 Pricing and Revenue Management in a Supply Chain

Revenue management uses differential pricing to better match supply and demand and increase the SC profits. Traditionally, firms have changed the availability of assets to match the supply and demand. But in the modern approach, pricing is used as a lever to reduce the mismatch between supply and demand and it is an easier one to do it, compared to an investment in SC assets.

Revenue management increases firm's profits by using differential pricing mechanism properly and retaining the valuable customers more satisfied through greater asset availability. It is effective for multiple customer segments each placing different values on the SC asset, perishable items, seasonal demand and bulk & spot customers. Optimization is to be applied in each case to obtain effective revenue management decision.

1.9 Coordination in a Supply Chain

The decisions, policies, actions or approaches of SC partners which lead to the benefit of the entire chain can be termed as SC coordination and it is essential for the success of SCM. Lack of coordination occurs if different stages of SC focus on optimizing their own objectives or if information is distorted as it moves across the SC. The effect of lack of coordination affects manufacturing cost, inventory cost, replenishment rime, transportation cost, labour cost for shipping and receiving, level of product availability and relationships across the SC adversely. That means the overall performance of SC is affected adversely due to lack of coordination. The awareness about the common obstacles to SC coordination is required to manage the same. Local optimization within functions or stages of an SC, improperly structured sales force incentives, information sharing obstacles, operational obstacles and pricing obstacles are some of the important issues of SC coordination. The method to achieve coordination among SC members is to implement appropriate coordination mechanisms, such as SC contracts, joint decision making, and information sharing and information technology. The managerial levers to achieve coordination are: i) aligning goals and incentives ii) improving operational accuracy iii) improving operational performance iv) designing pricing strategies to stabilize orders and v) building partnership and trust. The last one is a qualitative coordination mechanism and it is required throughout the SC along with any other mechanism for the overall success of any SC.

SC contracts are one of the major categories of coordination mechanisms. Appropriate SC contacts provide a platform to enable SC to resolve almost all issues among their partners. Designing and implementing effective contacts is a great challenge and it is one of the factors that decide the success of any SC. The key steps in designing effective SC partner ships are: i) assessing the value of the relationship to highlight the contribution of each player and expected benefits for each player ii) identifying the operational roles and decision rights for each party to acknowledge the roles, responsibilities and authority of each player in SC iii) creating effective contracts to get the expected results iv) designing effective conflict resolution mechanism to manage any dispute on any issue raised by any player in the SC. Price discounts, delay in payments, buy back, revenue sharing, and quantity flexibility contracts are some of the examples of SC contacts.

Information sharing is one of the major coordination mechanisms and SC partners can benefit by sharing information on sales, demand forecasts, inventory levels and marketing campaigns. Inaccurate and distorted information leads to a phenomenon where the fluctuation in orders increases as they move up the SC from retailers to wholesalers to manufacturers to suppliers and it is called bullwhip effect. The bullwhip effect reduces the profitability of an SC by making it more expensive to provide a given level of product availability. Figure 1.8 shows the occurrence of bullwhip effect in an SC.

Building strategic partnership and trust within an SC is very important for the effective implementation of any other coordination mechanism. The presence of flexibility, trust, and commitment in all parties helps an SC relationship to succeed. Good organizational arrangements, especially for information sharing and conflict resolution, improve chances of success. The success of any SC relationship depends how fairly a stronger player treats the weaker. The issue of fairness is extremely important in the SC context as most of the relationships will involve parties with unequal power. SC relationships are either based on power or trust and trust based relationship will sustain for long with fruitful results and others may collapse at any time. The trust between SC partners can be developed over time as a result of a series of interactions.

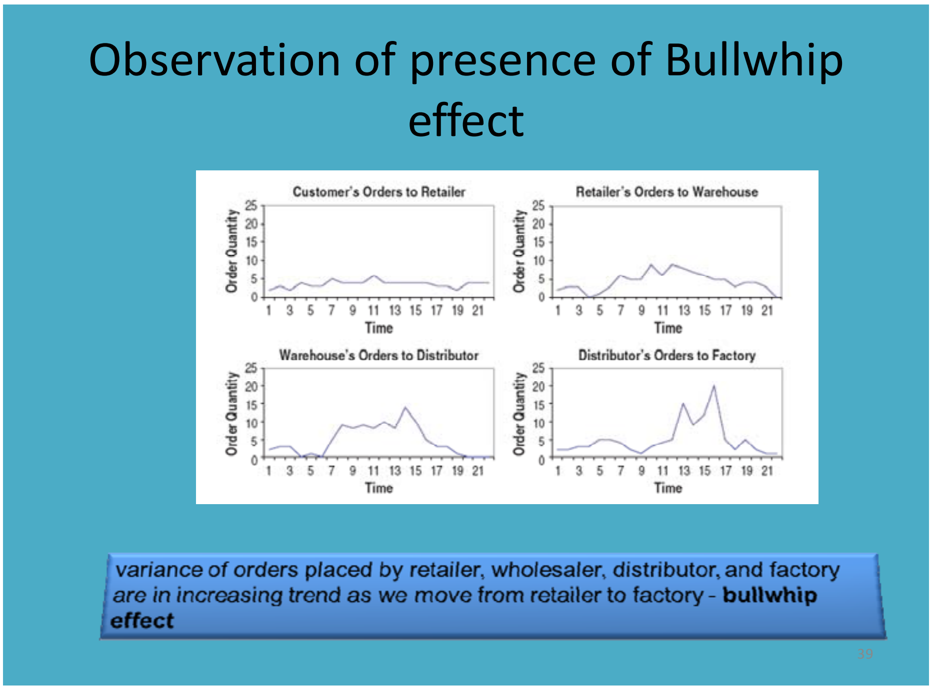

Figure 1.8: Order fluctuations at different stages of Supply Chain (Chopra and Meindl, 2004)

The importance of information technology (IT) in an SC is very high in the present business environment. Information is the driver that serves as the glue to create a coordinated SC.IT provides the tool to gather this accurate information on time and to analyse it to make the best SC decision. IT supports us to enable the interaction between organizations and with customers. Proper IT systems not only allow the collection of accurate data on time across the SC, but also the analysis of decisions that maximize the SC profitability. E-business is an application of IT and it is the execution of business transactions through the internet. E business makes all the process in a firm as well as in entire SC more responsive and efficient.

1.10 The Problem

The research on SCM is strongly related to SCC. It indicates the importance of this area without which complete success of SCM is not possible and hence SCC can be considered as the backbone of SCM. The various steps to achieve the SCC in practice are: i) understand the existing SC ii) list out the areas of lack of coordination iii) analyse the obstacles iv) identify the appropriate coordination mechanism v) apply modelling and analysis to understand the effect of coordination mechanism vi) get top management commitment for implementing the same vii) get resources for coordination viii) focus on communication between all stages and try to achieve it in the entire SC network ix) use technology to support the coordination mechanism x) share the benefits of coordination equitably xi) maintain the relationship and trust among SC members for long term success. The importance of coordination to improve the SC performance emphasizes the necessity to explore various issues of SCC to make the concept and practice of SCM more useful to all the users.

Because of the above, it is required that the study of the effect of various categories of mechanisms individually and in combination under different business cases be carried out to ensure strong SCC among SC members and thereby to improve SC performance. Supply chain contracts and Information sharing are two categories of mechanisms considered in this study to enhance the coordination and thereby to improve the performance. Under supply chain contracts, price discount and delay in payment are the two mechanisms considered individually and in combination. Because, customers are more familiar and easily attracted or motivated as both the mechanisms provides direct monetary benefits and hence firms are more concerned about these two mechanisms. Information sharing is the backbone of all other coordination mechanisms as it supports all the activities or operations to perform well. Different cases of information sharing are used separately and a combination of all in one. When confronted with the problem of choosing the coordination mechanisms, we have given importance to choosing simple and more widely used mechanisms in this study.

Accordingly, the problem for this research work was formulated and decided to study the following.

- Effect of combination of 'price discount' and 'delay in payment' on SC performance on a three level SC
- Effect of 'price discount and delay in payment' individually and jointly on a dynamic networked SC
- Effect of various types of information sharing on SC performance and the comparison between each other in detail using simulation game with live players.
- Effect of above mentioned coordination mechanisms on SC performance under lost sale and backorder cases
- Sensitivity of system parameters on supply chain performance.

1.11 Objectives of this Research Work

The importance of supply chain coordination and mechanisms found during the literature survey motivated us to select the same as the topic for the research. To solve the problems mentioned above, the following primary objective was targeted and to meet the primary objective, studies were conducted with certain secondary objectives as follows.

Primary Objective

- To study the performance of a multi-level supply chain while using selected coordination mechanisms

Secondary Objectives

- To study the performance of a three level supply chain while using 'price discount and delay in payment' jointly as coordination mechanisms using mathematical modelling.
- To study the performance of a three level networked supply chain while using 'price discount and delay in payment' jointly as coordination mechanisms under lost sale and backorder cases using simulation modelling.
- To study the performance of a four level supply chain using 'Information sharing' as coordination mechanism under lost sale and backorder cases using a simulation game with live players

1.12 Structure of the Thesis

The structure of the remaining part of the thesis of this research is given in this section. The whole thesis is divided into six chapters. The second chapter of this thesis deals with 'literature review' in the area of supply chain coordination (SCC) & mechanisms. The third chapter explains the performance of a three level SC while using 'price discount and delay in payment' jointly as coordination mechanisms using mathematical modelling. The fourth chapter describes the performance of a three-level dynamic networked SC while using 'price discount and delay in payment' jointly as coordination mechanisms under lost sale and backorder cases using simulation modelling. The fifth chapter discusses the performance of a four level SC using 'information sharing' as coordination mechanism under lost sale and backorder cases using a simulation game with live players. The sixth chapter focused on the limitations, overall conclusion and scope for future research.

Chapter 2

LITERATURE REVIEW

Contents

2.1 Introduction

According to the Council of Supply Chain Management Professionals (CSCMP), Supply Chain Management (SCM) encompasses the planning and management of all activities involved in sourcing, procurement, conversion and logistics management. It also includes coordination and collaboration with channel partners, which may be suppliers, intermediaries, third-party service providers, or customers. Supply chain management integrates supply and demand management within and across companies. Most of the time, many different organizations are involved in different stages and they need to work together to create value and improve SC performance. Managing all functions in different stages along the whole chain – from the supplier's supplier to the customer's customer – requires a great deal of coordination among the players in the chain. The objective of every SC is to maximize the performance of the SC. SC performance measures may be classified into two types (qualitative and quantitative). SC profit/cost, service level, etc. comes under quantitative category and the satisfaction of customers and other SC members comes under the qualitative category. SCs are generally complex and are characterized by numerous activities spread over multiple functions and organizations, which pose interesting challenges for effective SC coordination. Achieving coordination is a big challenge for any SC as it may involve multiple firms with different policies, priorities and objectives. As SC members are often separate and independent economic entities, a key issue in SCM is to develop mechanisms that can align their objectives and coordinate their activities so as to obtain improved system performance. Li and Wang (2007) provide appropriate coordination mechanisms based on SC decision structure and nature of demand. Arshinder et al. (2008) also did a similar study regarding SC coordination issues and available mechanisms in the literature to reveal the importance of SC coordination. Xu (2006) conducted a study on SC coordination and cooperation mechanisms with an attribute based approach and developed a framework that enables organizations to select appropriate coordination mechanisms, based on relative cost and the characteristics of their specific operating environment. Hendricks et al. (2007) conducted an empirical study on the impact of enterprise systems such as Enterprise Resource Planning (ERP), Supply Chain Management (SCM) and Customer Relationship Management (CRM) on corporate performance. They found that ERP systems provide some improvements in profitability but not in stock returns and adopters of SCM system experience positive stock returns as well as improvements in profitability and there is no evidence of improvements in stock returns or profitability for firms that have invested in CRM. They also concluded that although these findings are not uniformly positive across the different enterprise systems, no evidence of negative performance is found out in their study.

A generally accepted goal for an SC is to maximize SC surplus. For this in an SC consisting of many firms with different ownership/management linked to each other, close coordination is essential. The goal is total SC optimization and not individual firm optimization to obtain a win- win situation for all members in an SC. The decision taken by any SC member will affect the performance of the other members and finally the SC. This shows the significance and necessity to study coordination in SC.

The literature review chapter is devoted to:

i. Present the studies on Supply Chain Coordination (SCC)

ii. Identify the issues of Supply Chain Coordination

iii. Report the available mechanisms and methodologies for coordination

iv. Point out the gaps in the area of SCC and mechanisms

v. Discussion on Supply Chain Performance Measurement

2.2 Supply Chain Coordination

SC coordination (SCC) means that collaborative working for joint planning, joint product development, mutual exchange of information & integrated information systems, cross coordination at several levels in the companies on the network, long term cooperation and fair sharing of risks and benefits (Larsen, 2000). Another perspective on SCC is that it is a win/win arrangement that is likely to provide improved business success for all parties (McClellan, 2003).

During the literature survey in the area of supply chain coordination, it is found that there are some key issues in different areas related to supply chain coordination. On further in depth analysis, sub factors of these issues of supply chain coordination are also revealed. Even though most of these sub factors under each key issue are interrelated, each of these sub factors is relevant in the area of supply chain coordination and are to be addressed further to improve the performance. For example, order quantity and replenishment are components of inventory and which one is to be varied as a decision variable in the area of inventory control depends on the methodology to be followed. So, each one has to be addressed separately and to some extent, it is addressed in the literature to improve the performance of SC using proper coordination mechanisms. Similarly, two key issues: 'information sharing' and 'technology' given in Figure 2.1 are different as information sharing can be implemented with and without technology and both the situations have to be analysed to understand the effect of each one and studies of this kind are available in literature.

The necessity of this classification is to understand and analyse the coordination issues and to understand how they have been solved to improve the performance of SC. This is also useful to understand the effect of various coordination mechanisms on supply chain performance. The succeeding sections discuss about the classification and related studies of SC coordination issues.

Surveying the literature, SC coordination issues could be classified into quantitative and qualitative category. Quantitative issues may be classified into five topics namely, 1) operations 2) pricing 3) information sharing 4) technology and 5) disruption. These issues may be further classified into various sub topics. Different topics of quantitative issues in SCC are identified as shown in Figure 2.1. Qualitative issues are behavioural and ethical part of SC which is also important for the improvement in SC performance. In this literature review, studies on quantitative issues are addressed.

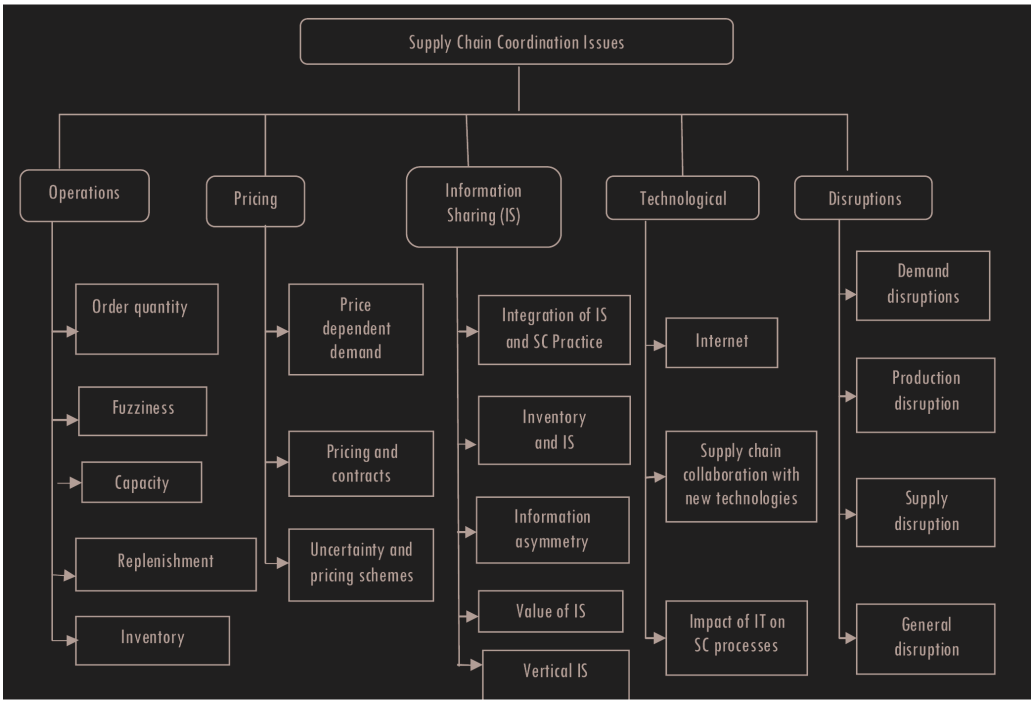

Figure 2.1: Classification of Supply chain coordination issues (quantitative)

In the next succeeding section, the first category of quantitative issues dealing with operations and its sub categories are discussed.

2.2.1 Operation

It is one of the most important areas of SC coordination which may be again classified into different sub categories, such as order quantity, fuzziness, capacity, replenishment and inventory. The recent works related to all these subcategories including coordination mechanisms are explained in the following sections.

2.2.1.1 Order quantity

Order quantity is linked to production batch size, price, inventory, transportation etc. Therefore it forms a key variable to be decided between two adjacent members in an SC. Various mechanisms are used to coordinate the order quantity in an SC system under different context. Most of the studies in the literature are based at a two level SC system as it is the basic structure of any SC. In such a system where the demand and lead time is fixed, a mechanism called delay in payment is used to coordinate order quantity (Jaber et al., 2006[b]) and thereby to minimize the local costs and that of the chain. Coordination using a quantity discount policy under multi period and probabilistic customer demand with shortage cost allowed (Li et al., 2006) is also available in the literature. Profit sharing mechanism of some nature is found in almost all studies to ensure equal rate of return on investment for each player. Sarmah et al. (2007) developed a coordination mechanism through credit option and discount policy such that both parties can divide the surplus equitably after satisfying their own profit targets. They also proved that financially stronger player prefer credit policy and weaker selects discount policy for coordination. Numerical and empirical analysis of influencing factors, such as annual demand, ordering cost, carrying cost, receiving cost, cost rate of losing flexibility, production rate and fixed set up cost on ordering and shipment policy (Kelle et al., 2007) available in literature is useful for taking optimal decisions for managers in actual practice.

Hsu et al. (2008) did a work on SC dealing with short life cycle products & variable selling price and developed an integrated strategy consisting of proper information sharing and a compensation mechanism. According to Jaber and Goyal (2009), coordination of a four-level SC consists of multiple buyers, a vendor (manufacturer), multiple tier-1 suppliers, and multiple tier-2 suppliers with a common and optimal cycle time for all non identical retailers and also through compensation by offering quantity discounts to entice the retailer to order more than EOQ. Coordination for an SC which deals with newsvendor-type-products is another issue found in this area. Zhou et al. (2009) investigates such a system with two ordering opportunities and partial backorders in which excess demand after the first order is partially backlogged. In this case, two policies are proposed for coordination: 1) a two-part-tariff policy when the buyer pays all the manufacturing cost 2) a revised revenue sharing contract when two parties share the cost. Joint decision making regarding order quantity and reorder point is very important in an SC. For this purpose, Chaharsooghi et al. (2010) developed an incentive scheme based on credit option in which buyer can use it with the condition of jointly agreed order quantity and reorder point.

2.2.1.2 Fuzziness of Demand

Fuzziness is a complex issue in SC coordination and studies regarding this issue are fewer in literature. The effect of fuzziness of demand can spread over the different stages of SC and reduces its efficiency and responsiveness. Petrovic et al. (2008) considered a single product inventory control in a Distribution Supply Chain (DSC) which operates in the presence of uncertainty in customer demands. In this study, demands are described by imprecise linguistic expressions and modeled by discrete fuzzy sets and inventories at each facility within the DSC are replenished by applying periodic review policies with optimal order up-to-quantities. An iterative coordination mechanism was proposed for changing the review periods and order up-to quantities for each retailer and the warehouse to minimize the cost. Xu et al. (2009) also did a work on the fuzziness aspect of demand uncertainty. Fuzzy numbers were used to depict customer demand in this study and investigate the optimization of the vertically integrated two - stage SC under perfect coordination and non coordination case. In the absence of a clear command and control structure, a key challenge in SC management is the coordination and alignment of SC members. Ryu et al. (2009) used a news vendor model and a fuzzy approach to quantify the cost of this misalignment and to asses the impact of various coordination policies.

2.2.1.3 Capacity

Production capacity and its utilization is a key issue in SCM. Lee and Rhee (2007) examined return policy in a newsboy framework in the assumption that both the supplier and the retailer have limited and stochastic salvage capacities. To handle this issue, three mechanisms are proposed: i) The manufacturer's buy back with early salvage capacity (BES) - compensating the retailer for all the retained leftovers after buy back; ii) buy back with price protection (BPP) - compensating for the fraction of the retained leftovers that the retailer salvages after buy back; iii) buyback with final salvage subsidy (BFS) - compensating for the remaining leftovers after the retailer's salvage. Insufficient production capacity is another problem for coordination. Sinha and Sarmah (2007) developed a Mathematical Model (MM) to analyze the situation of the lost sales when the supplier's production capacity is less than the annual demand of the retailer. Here, the supplier can procure from external source and satisfy the requirements of retailer. Li and Liu (2008) developed an extended newsboy model in which the retailer can place a second order to avoid the stock out where manufactures reserve capacity for the retailer's second order is limited. They designed a coordination mechanism and a profit allocation policy (price discount and profit allocating factor) to get more SC profit and allocate the same properly among players. Coordination is also possible for an SC in which manufacturer's operations undergo learning based continuous improvement (Jaber et al., 2010). It is characterized by enhancing capacity utilization, reduction in set-up time and improved product quality.

2.2.1.4 Replenishment Policy

The issue 'replenishment' consists of deciding order quantity, lead time and reorder point. Joint decision making is a suitable mechanism to manage this issue. Chung and Wee (2007) developed an optimal replenishment policy using a simple algebraic method to solve a three stage SC inventory problem with backorder considering JIT delivery. A procedure for coordinating the inventory replenishment, production and shipping decisions for a single product in an SC (Banerjee, 2007) consisting of a single producer with multiple retailers and suppliers is also suggested in the literature. Such coordination is achieved by linking the inventories at the different echelons of the chain through integrated decision making. Chen and Kang (2007) developed the integrated models with the permissible delay in payments for determining the optimal replenishment time interval and replenishment frequency. SC models for trade credit issues in the existing literature always assume the items produced as perfect. But, Chen and Kang (2010) developed integrated vendor–buyer models that consider a permissible delay in payment and products of imperfect quality to determine the optimal solutions of the buyer's order quantity and the frequency for each vendor's production run.

2.2.1.5 Inventory

Management of inventory is actually a separate topic of study and is very important in any SC system as it causes the storage cost and holding cost. Luo (2007) proposed a vendor – buyer with a single product to analyze the benefit of coordinating SC inventories through the use of credit period. Under this strategy, the vendor requests the buyer to alter his current order size through a proper compensation and also though order size dependent credit period mechanism such that the vendor can benefit from lower setup, ordering and inventory holding costs. Shin and Benton (2007) conducted a study in this area and developed a quantity discount model (buyer's risk adjustment model) which allows the supplier to offer discounts that capitalize on the original economic lot sizes and share the buyer's risk of temporary overstocking under uncertain demand.

Wong et al. (2009) detailed how a sales rebate contract helps to achieve SC coordination. This study proposes a model for an SC consisting of a single supplier serving multiple retailers in a VMI partnership which facilitates the application of sales rebate contract. The proposed model demonstrates that the supplier gains more profit with competing retailers (with a demand function depending on all retailer's prices) than without (with a demand function sensitive only to their own price) as competition among the retailers lowers the prices and thus stimulates demand. The study conducted by Kelle et al. (2009) focused on the inventory related costs that can be influenced by adjusting the ordering, setup, and delivery policy to the random yield which is still prevailing in several industries. This study showed that it is not the average yield but the yield uncertainty that plays the critical role mainly in providing an appropriate service level and also in finding the optimal shipment and setup policy.

2.2.2 Pricing

It is another important issue of SC coordination which can also be divided into subcategories. They are price dependent demand, pricing and contracts, uncertainty and pricing schemes. It is actually a key issue as it normally decides the customer demand. Studies related to these are discussed in section below.

2.2.2.1 Price Dependent Demand

Price elasticity of demand is a very fundamental principle of economics and is widely discussed in the literature. Price dependent demand is a significant issue in SCC. The solution is to find out the optimal price discount and selling price to increase the profit. In the literature, for a three-level SC model with price dependent demand, an all unit price discounts scheme is used to coordinate order quantities (Jaber et al., 2006[a]) and thereby to maximize the SC profit . Hsieh et al. (2010) also analyzed the coordination of ordering and pricing decisions in a two stage distribution system with price sensitive demand through short-term discounting under two types of demand; linear demand in price and constant elasticity demand in price. They found that for homogeneous retailers, the player's profits have similar characteristics under both the cases of demand but have different trends for heterogeneous retailers.

Another study found in the literature is the coordination of cooperative advertisement in a manufacturer- retailer SC with price sensitive demand (Yue et al. 2006) and the manufacturer offers price deduction to customers. Game theory was used for analysis and the optimal price deductions are determined. Qi (2007) also studied an SC with price sensitive demand but with multiple capacitated suppliers to maximize the profit by determining an optimal selling price. It is proved that the problem is NP-complete, and proposed a heuristic algorithm and a dynamic programming algorithm and tested by computational experiments.

Many more inventory models under different contexts with price sensitive demand are reported in literature. A finite time horizon inventory model for deteriorating items with price and time dependent demand under permissible delay in payment (Tsao et al. 2008) is developed. The analysis found the optimal price, promotional effort and replenishment quantities throughout a multi-cycle planning horizon to maximize the net profit. Ho et al. (2008) formulated an integrated supplier-buyer inventory model with the assumption that the market demand is sensitive to the retail price. The supplier offers two payment options: trade credit and early payments with discount price to the buyer. By analyzing the total channel profit function, they developed a solution algorithm to determine the best payment period, optimal retail price, order quantity and the number of shipment per production run from the supplier to the buyer.

2.2.2.2 Pricing and Contracts

Coordination of various parameters using different contracts with certain rules of pricing under multilevel structures and dynamic operating conditions of an SC system was found in the literature. A combination of coordination mechanisms consisting of Quantity Discount (QD) and Handling – Charge Reduction (HCR) schemes was used in literature for a manufacturer supplying numerous heterogeneous retailers (Lau et al., 2008).The analytical and numerical analysis in that study reveals the following i) an optimal QD scheme will have a high enough price break so that extremely few retailers will be big enough to get a 'free' discount and ii) an optimal HCR scheme produces practically the same magnitude of expected total gains as an optimal QD scheme. Revenue sharing contract is also a good contract for coordinating an SC comprising one manufacturer and two competing retailers (Yao et al., 2008) that faces a stochastic demand before the selling season. In this case, the retailers determine order quantity and retail price and the manufacturer designs revenue sharing contract. Adopting the classic news vendor problem model framework and using numerical methods, this study found that provision of revenue sharing in the contract can obtain better performance than a price-only contract. Ding et al. (2008) studied how to fully coordinate a three level SC with the so-called flexible return policy by setting the rules of pricing. With this contract, unsold products or used modules disassembled from the unsold products are returned level by level from the retailer to the upstream firms and each firm shares the loss due to the overstock.

Cooperative advertising is another good contract in practice by which advertisement cost has to be shared by both the manufacturer and the retailer. Xie and Wei (2009) addressed channel coordination by seeking optimal cooperative advertising strategies and equilibrium pricing in a two-member distribution channel. In this study also, a game theoretic approach is used for modelling and analysis. Integration of consumer return policy and manufacturer buy back policy within a modeling frame work is a new approach in the literature. Xiao et al. (2010) investigated coordination of a two stage SC facing consumer return using a buyback/markdown money contract under partial refund policy and found that it plays an important role in the decisions and profitability of the players.

2.2.2.3 Uncertainty and Pricing Schemes

There are a number of cases in the literature where uncertainty and pricing schemes play an important role in the SC coordination. In the recent literature, instead of simple price discount, pricing schemes/pricing schedules are used to coordinate an SC as the degree of uncertainty and dynamism has become very high. Lau et al. (2007) examined how a dominant retailer should operate when his knowledge of manufacturing cost is imperfect. They devised optimal decisions to be taken by retailer and a reverse quantity discount scheme that a dominant retailer can offer to the manufacturer. They showed that it is effective when nature of demand is linear and ineffective when iso-elastic. Lee (2007) designed and tested a model to study the effects of manufacturer and a discount outlet coordination in SC stocking, pricing and promotional markdown operations (product sold in normal sales period and subsequent leftovers markdown sale period). The study provided a numerical analysis to learn how and when coordination helps to increase profits and indicates that the centralized approach outperforms the decentralized one on every occasion.

Uncertainty and competition are very common in business. So the study on the impact of price discount contracts and pricing schemes on the dual channel SC competition (Cai et al., 2009) in an online direct channel is very significant. Coordination through simple discount policy may not be an efficient solution when the system contains a high degree of uncertainty. So, in such cases, multi pricing schedules to adopt global optimal policy (Sinha and Sarmah, 2010) are suggested in the literature.

2.2.3 Information Sharing

It is unavoidable and a prominent issue of SC coordination which connects various stages of SC to achieve better performance. This issue may also be subdivided into different groups like integration of Information Sharing (IS) and SC practice, inventory and information sharing, information asymmetry, value of information sharing, and vertical information sharing. Each category is discussed below.

2.2.3.1 Information Asymmetry

Information asymmetry is a common issue in almost all cases of SC. Some of the cases are found in literature. A critical assumption made throughout the SC literature in this area is that the supplier has complete knowledge about the buyer's cost structure. Sucky (2006) provided a bargaining model with asymmetric information about the buyer's cost structure assuming that the buyer has the power to impose its individual policy. Xu and Zan (2009) studied and analyzed the principle-agent problem under fuzzy information asymmetry condition using the theory of principal-agent (enterprise–seller) and incentive mechanism assuming that the demand depends upon the agent's effort level and the fuzzy market condition and derived an optimal contract for coordination. Esmaeili et al. (2010) also did a work on asymmetric information structure in which the seller's setup/purchase cost is unknown to the buyer and the buyer withholds certain information related to market demand. In this study, sharing of marketing expenditure is used as an incentive strategy to reveal information and modeled using game theory.

2.2.3.2 Integration of Information Sharing and Supply Chain Practice

Effective integration of information sharing (IS) is essential to improve the performance in an SC. Proper inter-organizational information sharing (IIS) improves SC performance; but it is a very difficult task to set up a supply network (SN) with the appropriate level of IIS as SNs tend to evolve over time, and are usually not the result of a master plan by any firm. Therefore firms need guidance to utilize resources effectively and implement IIS capabilities properly so that the performance of the individual firms and the whole SC improves a lot. Samaddar et al. (2006) focused on network configuration and partner goal congruence and their potential influence on IIS. Zhou and Benton (2007) did a statistical analysis to analyze the integration of information sharing and SC practice. Sezen (2008) investigated the relative effects of SC integration, SC information sharing and SC design on SC performance.

2.2.3.3 Value of Information Sharing

Literature on the role and value of information sharing helps us to understand its significance. Cachon and Fisher (2000) compared the traditional policy and sharing full information policy with one supplier and N identical retailers and found that SC costs are reduced significantly with information sharing. Viswanathan et al. (2007) investigated the value of various information exchange mechanisms. They concluded that planning inventories based on the planned downstream order schedules resulted in the lowest average inventory compared with demand information exchange mechanisms in a four–echelon SC under a material requirement planning framework. Kaynak and Carr (2012) did an empirical investigation to analyse the relationships among information sharing efficacy between firms, coordination mechanisms between firms and the effects these relationships have on buying firm’s performance. They reported that when the sharing of information occurring along with coordination of the information between the SC partners provides an opportunity to discuss the information and gain the necessary clarity and completeness to make the information of value to the buyer's firm, resulting in improved performance. Ganesh et al. (2008) analysed the impact of consumer product substitution on the value of information sharing in SCs and showed that substitutability among products generally reduces the value of information sharing. Another study by Dong and Lee (2013) on the value of information sharing in an SC with seasonal customer demand process showed that seasonal effect has an important impact on optimal inventory policies of the supplier and replenishment lead time must be less than the seasonal period in order to benefit from information sharing. Wu and Cheng (2008) did a study to quantify the impact of information sharing on inventory and showed that both the inventory level and expected cost of the distributor and the manufacturer decrease with an increase in the level of information sharing. A study on actual industrial SC consisting of small-to- medium sized enterprises is conducted by Byrne and Heavy (2006).They highlighted the significant benefits achievable through the use of improved information sharing and forecasting techniques. A comparative study on the value of information sharing under different inventory policies in construction SC is done by Xue et al. (2011).They reported that Q system is better than P system under no information sharing and P system is better than Q system under information sharing for contractor's service level. Lee et al. (1997) conducted a study on the bullwhip effect in Supply chains and suggested that companies wanting to control the bullwhip effect have to focus on modifying the chain's infrastructure and related processes rather than the decision makers' behavior. They have identified four major causes of the bull-whip effect i)Demand forecast updating ii)Order batching iii)Price fluctuation iv)Rationing and shortage gaming and also suggested various initiatives and other possible remedies based on the underlying coordination mechanism, namely, information sharing, channel alignment, and operational efficiency. Lee et al. (2004) also conducted a study on information distortion in a supply chain and claimed that distortion may arise as a result of optimizing behaviors by players in the supply chain. On the normative side, the combination of sell through data, exchange of inventory status information, order coordination and simplified pricing schemes can help mitigate the bullwhip effect. Agrawal et al. (2009) studied the impact of information sharing and lead time on bullwhip effect and on-hand inventory and reported that some parts of the bullwhip effect will always remain even after sharing both inter as well as intra echelon information. Further, it also showed that the lead time reduction is more beneficial in comparison to the sharing of information in terms of reduction in the bullwhip effect phenomenon. Zhao et al. (2002) conducted a study on the impacts of information sharing and ordering co-ordination on the performance of a supply chain with one capacitated supplier and multiple retailers under demand uncertainty. They found that information sharing and ordering co-ordination significantly impact the supply chain performance in terms of both total cost and service level. It is also found that the value of sharing information and ordering co-ordination is significantly affected by demand patterns and capacity tightness.

With respect to the types of information sharing, Jonsson et al. (2013) conducted a study on point of sales data, customer forecasts, stock on hand data and found that sharing stock on hand information is valuable with stationary demand while customer forecast and planned order information are valuable with non-stationary demand. Chen et al. (2006) used demand information sharing with its updating at a later stage after the demand forecast is improved to study the performance of a two level SC. They proposed a risk sharing contract to compensate the loss due to over production at manufacturer and over stocking at retailer for the better performance of whole system. Sharing of forecast information is also found in the study of Savedi and Jain (2012) to face the ever increasing threats to its operations from the frequent disruptions in an SC. Apart from this, Ryu et al. (2009) evaluated the SC performance of two different types of information sharing methods: planned demand transferring method (PDTM) and forecast demand distributing method (FDDM) in terms of throughput, inventory level and service level. They found that FDDM performs better in terms of throughput and maintains lower inventory level when there is a high forecasting error or high demand variability. Another study to improve SC performance by sharing advance demand information(ADI) is conducted by Thonemann (2002) in which two types of ADI, aggregated ADI and detailed ADI are considered and they deduced the conditions under which sharing can significantly reduce the cost. They showed that both manufacturer and the customers benefit from sharing ADI, but that sharing ADI increases bullwhip effect. As found in earlier studies, Chen (2013) proved that complete information sharing is possible only with an appropriate contract to take care of the issues of SC partners on information sharing and they used revenue sharing contract in their study to support it. Inventory information sharing is another mechanism used in this area for the improvement of SC performance. Chan and Chan (2009) did a simulation study with cascade information sharing approach in contrast to full information sharing on inventory in a multi-echelon SC and got a result almost equivalent to a complex procedure of full information sharing approach subjected to various service levels.

According to Pundoor and Herrmann (2006), there is a need for standard simulation elements to represent the activities in an SC. They described an SC simulation framework that follows the SC Operations Reference (SCOR) model. They used this framework to build simulation models that integrate discrete event simulation and spreadsheets. These simulation models are hierarchical and use sub models that capture activities specific to SCs. Jain and Ervin (2005) described an effort utilizing modeling and simulation for evaluating the improvements in business process and systems including a move towards e-business for a logistics and distribution SC and quantified the benefits out of it along with some insights applicable to SCM. Wong (2009) introduced the Data Envelopment Analysis (DEA) SC model in combination with Monte Carlo simulation to measure the SC performance in the stochastic environment and a GA-based heuristic technique to improve the prediction of the performance measurement. Bottani et al. (2012) presented a simulation model to assess the performance of supply networks, and investigated economic order interval and economic order quantity policies under several different operating conditions of the networks. They primarily focused on the comparison of different reordering policies in terms of their impact on supply network performance and derived some guidelines to identify the most appropriate reordering policy to be adopted in the network as a function of its operating conditions. Xu and Zhai (2010) focused on the fuzziness aspect of demand uncertainty for a two stage vertically integrated SC coordination problem. In this study, they used fuzzy numbers to depict customer demand and investigated the optimization under perfect coordination and contrast with the non-coordination case. Petrovic (2001) described a special purpose simulation tool, SCSIM, developed for analyzing SC behavior and performance in the midst of uncertainty. The uncertainties are described by imprecise natural language expressions and they are modeled in SCSIM by fuzzy sets. The two types of models combined in SCSIM are (1) SC fuzzy analytical models to determine the optimal order-up-to levels for all inventories in a fuzzy environment and (2) an SC simulation model to evaluate SC performance achieved over time by applying the order-up-to levels recommended by fuzzy models.

2.2.3.4 Vertical Information Sharing

The significance and effects of vertical information sharing on the supply chain coordination are also found in the literature. Yao et al. (2008) considered an SC consisting of one supplier and two Value-adding heterogeneous retailers with each retailer having full knowledge about his own value-added cost structure that is unknown to the supplier and the other retailer. Under the assumption that there is no horizontal information sharing between two retailers, they modeled an SC with a three–stage theoretic framework in which each retailer decides to vertically disclose his private cost information first and the supplier announces the wholesale price to the retailers in the second stage and finally the retailers optimize their own retail prices and the values added to the product. They obtained the conditions under which both retailers have incentives to reveal their cost information with the supplier and for not sharing their private information. The first attempt to incorporate buyer's expectations into SCC problem is by Karabat1 and Say1n (2008) in which they addressed the coordination problem in a single-supplier/multiple-buyer SC with vertical information sharing. They shaped each buyer's net savings expectations based on her limited view of the entire SC which consists of herself and the supplier only, and then incorporated these expectations into the modelling of the SC conducted by the supplier. They have considered both price discriminatory approach and non–price discriminatory approach to design the quantity discount schemes that achieve time coordination without any additional requirement for buyers to comply with the supplier's replenishment period in choosing their order quantities.

2.2.3.5 Inventory and Information Sharing

Literature also deals with how proper information sharing helps to coordinate under different inventory policies. Gavirneni (2006) considered an

SC consisting of one supplier with finite production capacity and a retailer facing independent and identically distributed demands (iid) from end-customers. Their study showed that SC performance can be improved by the supplier offering fluctuating prices and proper information sharing. Studies to reduce average ordering and inventory related cost under the centralized decision making paradigm where there is a single decision maker and complete information of the system are available in literature. Chu and Leon (2008) conducted a different study to analyze the problem of coordinating a single-warehouse multi-buyer inventory system with private information, and found a replenishment policy for each facility in the system, such that the total average ordering and inventory-related cost of the entire system is minimized. Modified Power of-two inventory theory is used to develop a heuristic for coordinating the above inventory system under private information.

2.2.4 Disruptions

SC systems however well designed, will face disruptions in operations. Disruption happens due to various factors such as information sharing, technology, pricing, etc. But these disruptions are reflected in various stages/factors of operations such as demand, supply, production and some spread over more stages of supply chain in multiple forms which are presented under 'General Disruptions'. As we have dealt the above mentioned factors (Information sharing, technology, pricing) separately in the literature review, concerned issues are discussed under each category.

Disruption management is a comparatively new and challenging field. There are many disruptive accidents in the SC operations system, such as demand disruptions, production cost disruptions, supply disruptions and other general/multiple simultaneous disruptions which are explained briefly in this study.

2.2.4.1 Demand disruptions

Demand forecasting methods are available in plenty. But, the actual end customer demand may vary from the forecast one and this will cause demand disruptions at different stages of the chain. Demand disruption results in losses in different ways for each player in a chain. Xiao et al. (2007) investigated the coordination of an SC with one manufacturer and two competing retailers when the demands are disturbed. They analyzed the effects of the changed amount of market scales on the coordination mechanism and the optimal decision making. Apart from the case of competing retailers, coordination of SC under demand disruption with a dominant retailer (Chen and Xiao, 2009) is also available in literature. This SC model with one manufacturer and dominant retailer under demand disruption incorporated the deviation cost that affects the objective functions of the SC members. The analysis showed that linear quantity discount schedule is better when production cost is sufficiently low and when it is high, wholesale price schedule is better.

2.2.4.2 Production Cost Disruptions

Production cost disruptions may occur due to change in the cost of tools, technology, materials, variation in salaries & wages, production quantity, quality requirements, etc. Xu et al. (2006) studied an SC coordination problem under production cost disruptions. In this study, a single product is considered which requires two major operations and it was assumed that during the second operation, anticipated production cost has changed. In their study, modeling the production cost disruptions and their impacts, design coordination schemes under disruptions are discussed and developed expressions for optimal values of retail price, production quantity and optimal SC profit. Another study in this area is the coordination of two-level SC with production interruptions (Ahmed Saadany et al., 2008) to restore process quality. Three cases that describe the behavior of the manufacturer's inventory level were considered in this study. They are: 1) restore the production process after delivering a lot to the retailer 2) restore the production process before delivering a lot to the retailer and 3) restore the production process at ay time during production. This study suggested that order in smaller lots more frequently is better when production is imperfect.

2.2.4.3 Supply Disruptions

It needs the earliest and immediate attention as it is the starting point of any SC and without solving this issue properly, the system cannot move further. Yu et al. (2007) studied how the disruptive accidents affect the coordinated SC. Based on the SC coordinated by the negative incentive mechanism; they analyzed the impacts of supply disruption on the SC system by using simulation approach where two different distribution functions of random variable were used to express the supply disruption. They compared these two simulation results and suggested a possible coordination mechanism for handling supply disruption. It is very important to analyze that how sourcing can be done in the presence of SC disruption risks. Yu et al. (2009) examined the complexity of the sourcing decision in the presence of SC disruptions; in particular , the famous debate between single sourcing and dual sourcing is revisited by taking supply disruption risks into account under price sensitive demand and the market sale increases when a supply disruption occurs. This study indicates that sourcing decision depends on the magnitude of the disruption probability and also provides the closed form solutions and critical values to help the decision making process under disruption. Determination of optimal size of supply base considering the risk of supply disruption is a significant issue. Sarkar et al. (2009) determined the optimal size of supply base. They analyzed the risks of supply disruptions due to occurrence of super, semi super and unique events and formulated a model in a decision tree-like structure to determine the optimal size of supply base. The study of buyer's perceptions of supply disruption risks (Ellis et al., 2010) is also found in the literature. In this study, the validation of buyers' perceptions of magnitude of disruptions, probability of disruptions, and overall supply disruption risk facilitate the translation of situation to decision.

2.2.4.4 General/Simultaneous Disruptions

There are general or common disruptions and some of which can be recognized at the initial stage itself and the same solved so that it will be easier to tackle the major disruption occurring in between the various operations or stages. Tang (2006) presented certain robust strategies to enable SC to manage the inherent fluctuations efficiently regardless of the occurrence of major disruptions and to make an SC become more resilient in the face of major disruptions. The proposed strategies are postponement, strategic stock, flexible supply base, make or buy, economic supply incentives, flexible transportation, revenue management, dynamic assortment, silent product rollover.

Multiple disruptions are also discussed in the literature. Xiao et al. (2008) analyzed the coordination of an SC consisting of one manufacturer and two competing retailers with price competition, cost and demand disruptions and analyzed how disruption cost affects the two coordination mechanisms: all unit quantity discount and incremental quantity discount. Thus, strategies are formulated to handle both cost and demand disruptions. The effect of operational slack, diversification and vertical relatedness on the stock market reaction (Hendricks et al., 2009) to SC disruptions is another useful study found in the literature. This study used a sample of 307 SC disruptions announced by publicly traded firms during 1987-1998 to analyze the effect of various strategies on the stock market reaction to SC disruptions. Their analysis showed that more slack in the SC and high degree of vertical relatedness experience less negative stock market reaction and business diversification has no significant effect on the stock market reaction. But, geographically diversified firms experience a more negative stock market reaction. These findings surely influence the design and operation of SCs to mitigate the negative effect of SC disruptions.

Case studies related to management of disruption are also available in literature. Oke et al. (2009) conducted a case study of a US retail SC and categorized various risks into inherent or high frequent risks and disruption or infrequent risks. Finally, they found out some generic and specific strategies for handling various types of risks. Skipper et al. (2009) also examined the use of a strategic approach to minimize the risk exposure to SC disruption. Based on the sample used in this survey, top management support, resource alignment, information technology and external collaboration enhance the flexibility in the system and found that this flexibility can reduce disruptions.

2.2.5 Technology

SC coordination without proper technology is extremely difficult in a competitive and dynamic business environment. Information technology is a key issue to be considered in an SC without which the three main flows (product flow, information flow, fund flow) in an SC are not possible in an optimal manner. This issue can also be viewed as different groups which are Internet, SC collaboration with new technologies, and impact of Information Technology (IT) on SC process.

2.2.5.1 Internet

It is clear from the literature that Internet can be utilized for the coordination in different ways among SC members as it is the fastest and cheapest way for communication and source of information and economical. Internet companies extensively use the practice of drop-shipping. Netessine and Rudi (2006), developed a dual strategy whereby the retailer uses local inventory as a primary source (in which retailer stocks and owns the inventory) and relies on drop-shipping (in which the wholesaler stocks and owns the inventory and ships products directly to customers at retailer's request) as a back-up and model it as a non cooperative game among the retailers and wholesalers. They analyzed this model and obtained insights to the structural properties of the equilibrium solution to facilitate the development of recommendations for practicing managers. Now, regarding SC for the construction industry, a qualitative study is there in literature regarding coordination mechanisms for Construction Supply Chain (CSC) management (Xue et al., 2007) in the internet environment. This study defined the concepts of construction supply chain and CSC management and also the inter-organization problems that affect CSC coordination. They presented two types of Internet-enabled coordination mechanisms: market mechanism, such as auction contracting and coordination flow, including information hub and electronic market place, for improving construction performance and to accelerate the innovations in the construction industry.

2.2.5.2 Supply Chain Collaboration with New Technologies

In the SC coordination, quick response, timing, accuracy are very important which necessitate the SC collaboration with new technologies. In the literature, there is a statistical study on the impact of ERPII. Koh et al. (2008) presented a set of clear business benefits and impediments, hindrances to success through an extension of pertinent literature on ERP and through logical deduction (cause and effect) of the current literature on ERP II. The research identified three collaborative structures suitable to aid information exchange in a real-time collaborative scenario, namely joint ventures, networks and Japanese–style ‘purchasing partnership’. Another methodology/technique for SCC is distributed optimization. Gaudreault et al. (2009) studied the case of an SC made up of autonomous facilities (represented by software agents) that need to coordinate their manufacturing operations. The coordination problem represented as a tree by considering the entire coordination space (by generalizing the coordination mechanisms) can be optimized using a distributed tree search algorithm (e.g.SyncBB). This allowed for the exploration of alternative solutions by the agents while maintaining current business relationships, responsibilities and local decision making algorithms. This study found that SyncBB improved the quality of the solution compared to the current practice. The main contribution of this study is multi agent concurrent discrepancy search (MacDs) that uses the concept of discrepancy and permits the agents to find the optimal solution.

Radio Frequency Identification (RFID) features high storage capacity, remote access, excellent data security and multiple-tag reading. Pramatari (2007) provides an overview of SC collaboration practices and the way the underlying enabling technologies have evolved, from the classical EDI (Electronic Data Interchange) approach, to web-based and RFID-enabled collaboration. They derived interesting lessons regarding the suitability and criticality of the technological approach used to support collaboration, especially regarding the use of a centralized web-platform as compared to the EDI approach and to a decentralized solution based on web services. Lin (2009) constructed an integrated framework for the development of RFID technology in the logistics and SCM which includes the hierarchy of factors, structural procedure, and sequence of adoption.

2.2.5.3 Impact of IT on Supply Chain process

An analysis on the impact of IT on SCM is very much needed to take corrective measures for further improvement. Drawing from the resource-based view, Wu et al. (2006) proposed that IT-enabled SC capabilities are firm-specific and hard-to copy across organizations. This study provided a new perspective in evaluating IT investment in the SC process. The implications of the different types of institutional isomorphism, namely coercion, mimesis and norms, are explored from both the perspectives of firms that have taken the initiatives to adopt IT and those that have followed their SC partners to adopt IT. A Study on institutional isomorphism and the adoption of IT for SCM is very important topic. Lai et al. (2006) analyzed and discussed the implications of institutional isomorphism on the adoption of IT for SC management in their study. Fin and Oklahoma (2006) empirically investigated the moderating effects of firm size on the relationship between the level of IT adoption and three performance levels: operational, financial and strategic, for an apparel SC and found that firm size was a significant moderator variable for operational (lead time), but not strategic and financial performance.

Drawing from organizational theories of learning, Sanders (2008) proposed a model that evaluated how two patterns of IT use by suppliers (exploitation and exploration) impacts two specific types of coordination activities with their buyers (operational and strategic coordination). Using data from 241 first tier OEM suppliers in the computer industry, they found that each pattern of IT use directly promotes a specific type of coordination activity and to achieve a complete set of benefits, suppliers must ultimately use IT for both exploration and exploitation.

2.3 Simulation Modelling

Simulation is a very useful tool for predicting SC performance. Some of the advantages of SC simulation (Chang and Makatsoris, 2001) are i) it helps to understand the overall SC process and characteristics by graphics and animation. ii) able to capture system dynamics: using probability distributions, the user can model unexpected events in certain areas and understand the impact of these events on the SC. iii) It could dramatically minimize the risk of changes in planning process by what-if simulation process and the user can test various alternatives before changing the plan.

Simulation modelling helps the researcher to study the SC coordination with a realistic structure and operating parameters under dynamic environment. Kuhal et al. (2005) presented the development of conceptual models that can be used in the creation of four level SC simulation projects to study the collaboration practices. Ingalls et al. (2004) developed a system to aid professionals from management and logistics areas to evaluate the performance of SCs through computer simulation. Thierry (2010) also provided an overview of the main concepts that relate to simulation studies of SCM systems. They highlighted some of the modelling and simulation challenges with respect to SC design decisions, control policies, degree of systematic decomposition of SCM system and distribution level of the system with possible solutions. Swaminathan (1998) developed a SC modelling frame work to overcome the time and effort required to develop models with sufficient fidelity to the actual SC of interest. Using this approach, SC models are developed from software components that represents types of SC agents (e.g., retailers, manufacturers transporters etc), their constituent control elements (e.g., inventory policy), and their interaction protocols (e.g., message types). Min (2002) synthesizes past SC modelling efforts and identifies key challenges and opportunities associated with SC modelling. This study also provided various guidelines for the successful development and implementation of SC models. Persson (2002) presented a SC simulation study concerned with manufacturing of mobile communication systems to evaluate alternative SC designs with respect to quality, lead times and costs as the key performance parameters and to increase the understanding of the interrelationships among these and other parameters relevant for the design of the SC structure. Klimov (2008) investigated the problems related to SC risk identification and simulation based risk evaluation. Initially, this study dealt about the risk recognition in SCM and additional risks connected with SC reliability. In the second part of the study, a numerical example within which a simplified SC system is defined and corresponding risk evaluation is performed. Johansson et al.(2010) studied the issue of channel coordination for an SC consisting of one supplier and two retailers, facing stochastic demand that is sensitive to both sales effort and retail price and developed a decision support tool using simulation optimization for SC coordination with revenue sharing or buyback contract to find out the optimum decision variables. Paes (2012) proposed a framework to model a SC where each SC entity is modeled as a system, hierarchically composed of sub-systems to the required level of abstraction. Each system has operations which determine its inputs, outputs, time and capacity. The framework was tested in DELMIA V6 Production System. Performance is evaluated using system utilization, throughput, order fulfillment time, inventory collected during simulation. This framework allows incremental modelling and easy modification of system structure and operations. Lee (2002) considered the issue that SC systems are neither completely discrete nor continuous and developed a model with the aspects of both discrete event and continuous simulation.

Arena is one of the simulation softwares found in the literature to model the SC and it has been used in this research to model a network supply chain. Altiok and Melamed (2007) and Kelton et al.(2001) provide the details about various modules in Arena and how to model a system using Arena simulation software.

2.4 Mechanisms vs. Stages and Flows in Supply Chain

Different mechanisms used in literature at different stages of an SC for ensuring the smooth and efficient flow of product, fund and information to improve the performance of the system are summarized in table 2.1.

Table 2.1: Mechanisms corresponding to different Stages (S) vs. Flows (F) in a supply chain

F \ S	DESIGN	OPERATIONS	DISRUPTIONS
PRODUCT	*Joint market survey *Joint product design *Joint product policies & strategies, such as market promotion techniques	*Joint forecasting, ordering and replenishment policies *Joint contracts like buyback, quantity flexibility, quantity discount *Learning based continuous improvement	*Information technology *Robust strategies such as postponement, strategic stock, flexibility enhancement, make or buy, flexible transportation, assortment planning, etc
FUND	*Joint trade credit policies *Joint decision on trade off between cost and quality *Joint decision on technology for fund transaction	*Joint pricing schemes *Joint decision on profit sharing methodology *Joint price contracts, such as quantity discount , price discount, delay in payment	*Cost sharing *Robust strategies, such as economic supply incentives, revenue management via dynamic pricing and promotion, make or buy
INFORMATION	*Joint decision on technological investment for information sharing *Centralized/ decentralized structure *Design of supply network and inter organizational information sharing	*Joint information sharing on demand, inventory lead time production schedule, capacity, etc. *Information sharing tools like ERP, MRP, Email , EDI, RFID *Joint order and production policy	*Incentive schemes for information sharing *supply chain contracts , Joint decision making, information technology *Risk categorization and Risk mitigation strategy formulation

2.5 Policies and Risks in a Supply Chain

The different policies & influencing factors as well as their risks and decision option available in a supply chain are briefly depicted in figure 2.2.

I
II
III
IV

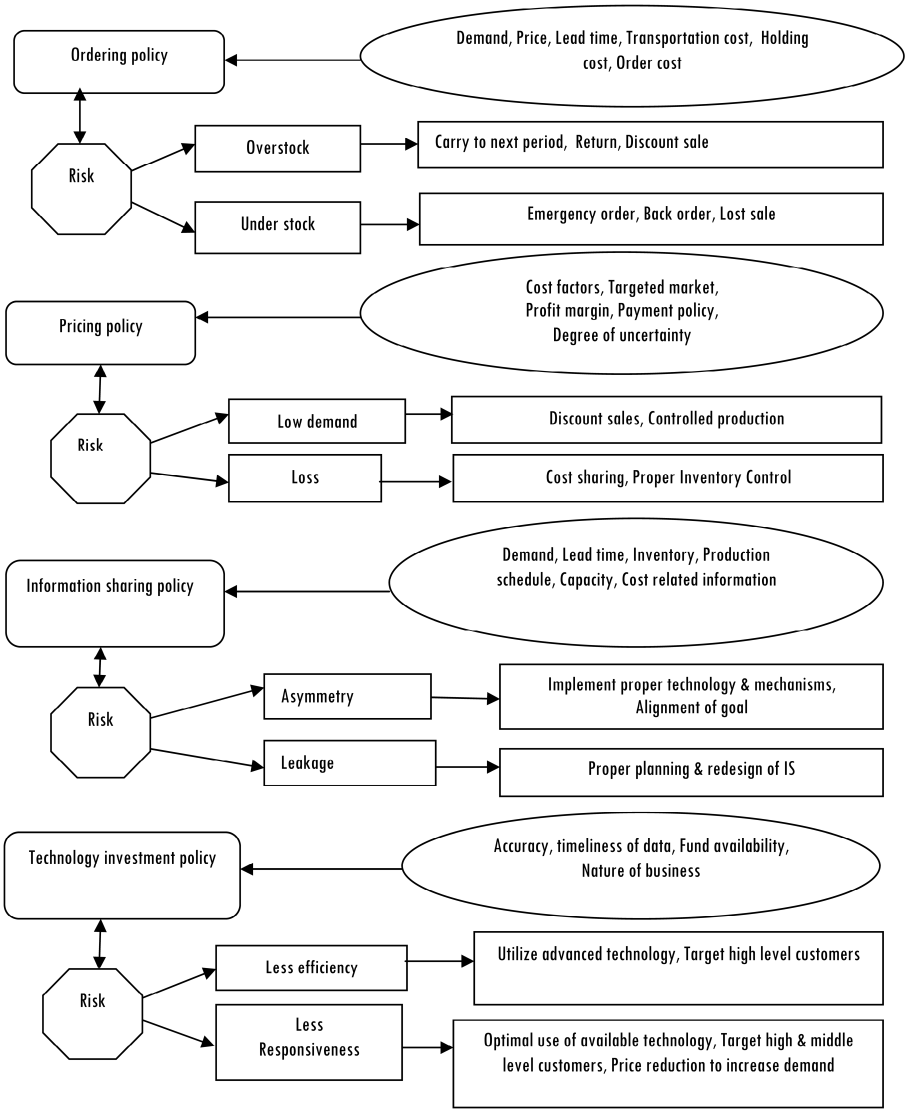

Figure 2.2: Influencing factors – Policies – Risks - Decision option available in a supply chain

2.6 Supply Chain Coordination Obstacles

The major drivers of SC performance are facilities, inventory, transportation and information. Each driver affects the balance between efficiency and responsiveness of an SC. So, the investment on drivers must be done based on the requirement of level of efficiency and responsiveness.

A consolidated form of the typical cases of SC coordination obstacles available in literature are provided in figure 2.3.These obstacles can be removed or minimized from the SC scenario using appropriate mechanisms. All these obstacles may not occur in each and every SC. Some of these are qualitative and others are quantitative in nature. However, these obstacles have been identified from different activities, interfaces and the number of levels in the SC. It has been realized that the obstacles of SCC and independent working of SC members lead to poor performance.

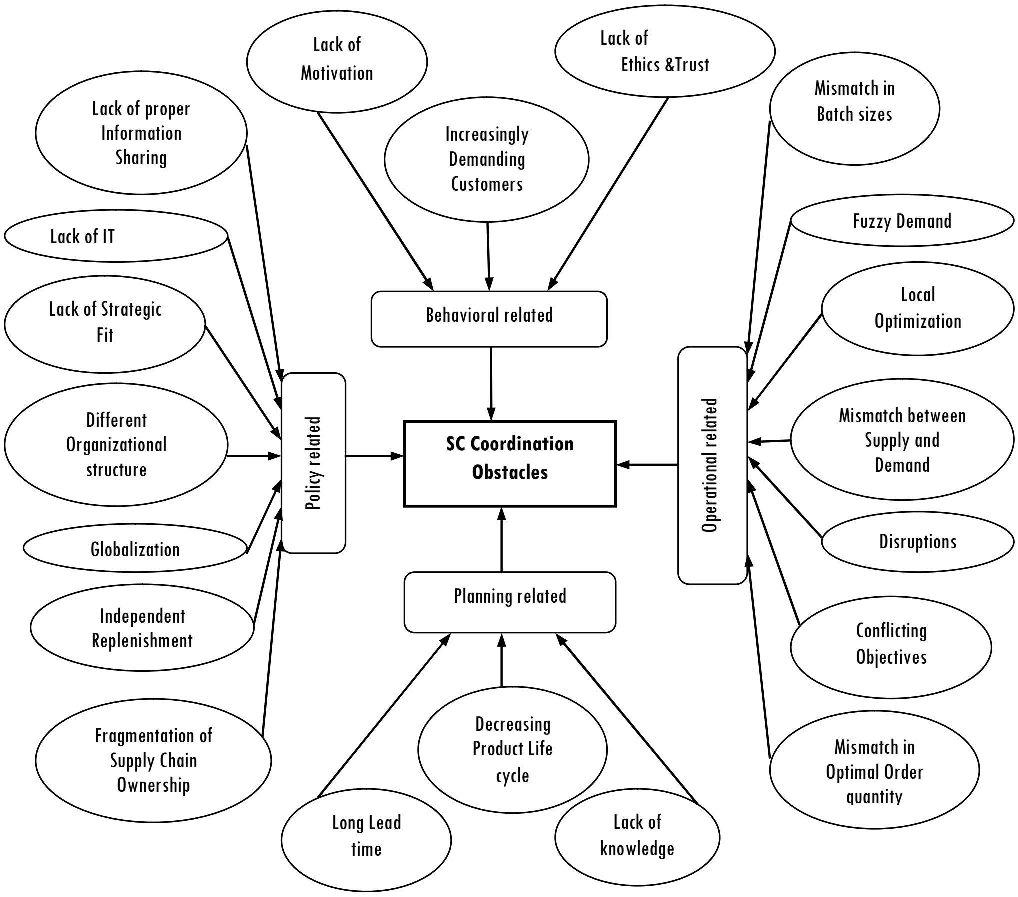

Figure 2.3: Supply chain coordination obstacles (Modified from Arshinder et al., 2008)

Basically, these coordination obstacles can be classified with respect to its areas as i) policy related ii) planning related iii) operation related. It is also clear from the literature that all the issues are interrelated and combination of mechanism may have to be tried to solve an issue. Operational and pricing issues are found most common in the supply chain coordination and information sharing is most probably a part of other issues. Even though ‘logistics’ is a separate area, of SCM, all the other issues can be found in the case of logistics also in different forms. IT issues are mainly a part of operational and information sharing areas. The studies in literature in the IT and SCC area provide the importance of proper implementation of IT without which the result can be opposite to that of desired one. Behavioral issue is qualitative in nature and it will have an effect on any issue throughout the supply chain coordination. Disciplines, such as SRM, CRM, and CRM are related to this area and proper execution of these management techniques along with other trust mechanisms can be a solution for solving behavioral issues. To have an overall improvement in SCC, a holistic, cooperative, and mutually trusted and risk sharing approach with other quantitative mechanisms is required.

2.7 Classification of Mechanisms

Table 2.2 shows various categories of mechanisms and examples under each category. Supply chain contracts are mainly meant for resolving issues, such as lot sizing, capacity utilization, and inventory management, pricing, etc. Information technology provides the tools to gather accurate and right information in a timely manner to analyse it to make the best supply chain decisions. It is a supporting mechanism for all others. Selection and implementation of IT is very important. Select an IT system that addresses the company’s key factors and take incremental steps and measure its value. It is very important that align the level of sophistication with the need for sophistication required considering the future also. It is to be ensured that use IT systems is to support decision making, not to make decisions. If these factors are not taken into consideration, IT will become rather a nuisance than an advantage. Information sharing helps the supply chain members to take appropriate decisions regarding any issue to improve the overall performance in this dynamic and competitive environment. But, if the information is not right, accurate and timely, the result will be negative. Joint decision making resolves almost all obstacles to coordination. But, there must be a trust and ethics mechanism along with Joint decision making policy. Otherwise, the dominant member may play over the other(s) and gain more advantage from coordination and finally the SC may not be successful. This is applicable for information sharing mechanism also. Mechanisms under miscellaneous category are of qualitative nature and are applicable to reducing different kinds of disruptions occurring in SC during the business process. The implementation of these mechanisms can also be done only after in-depth study of disruptions occurring during the process as it is random in nature.

Table 2.2: Classification of Mechanisms with Examples ((Modified from Arshinder et al., 2008)

Supply chain contracts	Information technology	Information sharing	Joint decision making	Miscellaneous mechanisms
i)Buy back ii)Revenue sharing iii)Quantity flexibility iv) Price discount v)Delay in payment vi Sales rebate vii)Multiple pricing schemes viii)Effective multi-stage- inventory linkage ix)Flexible return-policies x)Single, dual, and multiple sourcing xi)Consignment contract	i)Internet enabled mechanisms such-as Email, Online auctions & contracting, fund transactions and services Information hub ii)EDI iii)ERP iv)MRP v)RFID	i)Demand ii)Inventory iii)Lead time iv)Production schedule v)Capacity vi)Cost vii)Backorder viii)Point of sales data ix)Supply chain performance	i)cost aspects ii)Replenishment iii)Forecasting iv)Ordering v)Production-policies vi)Out sourcing vii)advertising viii)Pricing ix)Promotion-schemes x)Market research xi)Design collaboration	i)Management tools and techniques such as CRM,SRM, and ISCM ii)Dual sourcing iii)Economic supply iv)Incentives v)Postponement vi)Strategic stock vii)Flexible supply base ix)Make and buy x)Dynamic assortment xi)Silent product rollover xii) Learning based continuous improvement

From this literature review on supply chain coordination, it is clear that coordination in an SC is very important. Organizations follow some principles of supply chain management knowingly or unknowingly. It is essential to study different coordination mechanisms and find areas where they are effective, so that knowledge for conscious selection of coordination mechanism is created for users. There has been a lot of work in the area of SC coordination and bridging the gap between models with rigid assumptions and reality will be a constant challenge to researchers in this area. Figure 2.4 shows a framework for SC coordination study.

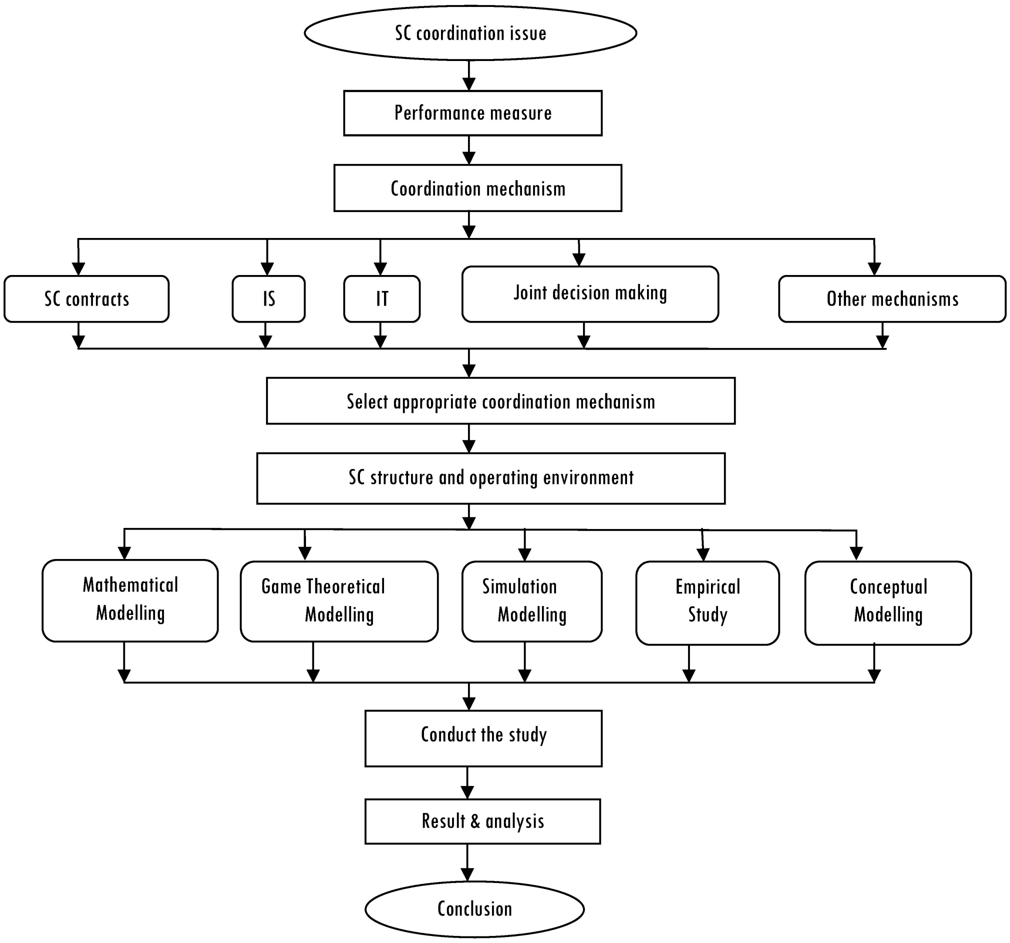

Figure 2.4: A framework for SC coordination study (Modified from Arshinder et al., 2008)

The above framework has been modified from Arshinder et al., 2008 based on the literature we have reviewed. During the literature review, we have found different coordination issues, various coordination mechanisms, and also different types of modelling approaches to solve the problem. We have consolidated the approaches of these studies and put in a framework expecting that to be useful for further supply chain coordination studies and some of these methodologies (mathematical modelling and simulation modelling) were adopted in our work.

This literature review is intended to open up the issues dealt in the recent past studies to get a picture about the present stage of SC coordination and further areas to be addressed. The details of various obstacles being faced by the different SC to achieve coordination, and mechanisms to overcome such issues are presented. Various categories of mechanisms are also provided in this chapter to get an overall idea about it. Finally, a framework to conduct an SC coordination study is also given to get an outline of how to start with and pursue the research work in the area of supply chain coordination.

As discussed in the preceding sections, a detailed literature survey was conducted in the area of supply chain coordination. During the literature survey, various gaps or topics still to be studied were found and it is decided to address the following gaps.

Individual studies on the effect of 'price discount and delay in payment' on a dynamic network SC were not available in the literature. It is to be noted that the combined effect of these mechanisms on a simple SC was also not found in the literature. As mentioned earlier, information sharing is very important to SCC. But, the effect of various types of information sharing on SC performance with the comparison between each other in detail was not available. Study on the effect of various types of information sharing on SC performance using simulation game with live players is also very important as it involves a reality factor of live players. So, this kind of study can be conducted to make it advantageous for the SC practitioners. Most of the businesses in the world have a characteristic of either lost sale or backorder. So, if the studies mentioned above can be conducted under these two cases, it will be very relevant and useful for the users as it was not available in the literature. Sensitivity analysis is really an essential part of these kinds of studies to make it really worthy to all related academicians and SC mangers. But, it is also not up to the required level in the literature. So, detailed sensitivity analysis also can be incorporated with above mentioned studies to be addressed in the research work. The decision to study and analyse the above mentioned gaps in the literature prompted us to have the objectives as mentioned in section 1.11 of chapter 1 in this thesis report.

2.8 Supply Chain Performance Measures and Tools

The classification of performance measures and tools are provided in Chapter 1 under the section 1.3.6.In this section, each one of the performance measures and tools are discussed as follows

2.8.1 Supply Chain Performance Measures

The performance measures related to various activities or operations (provided as subsections) of SC discussed under each category are highlighted in bold letters and explained below as discussed in Gunasekaran, et al., 2004.

2.8.1.1 Order plan

"**The order entry method**" is one of the measures under order plan which determines the way and extent to which customer specifications are converted in to information exchanged along the supply chain. "**Order lead-time**" is another measure which determines the total order cycle time, the reduction in which leads to reduction in supply chain response time. It is an important performance measure and source of competitive advantage as it directly interacts with customer service in determining competitiveness. "**The customer order path**" is the path that an order traverses is another important measure whereby the time spent in different channels can be determined. By analyzing the customer order path, non value adding activities can be identified so that suitable steps can be taken to eliminate them

2.8.1.2 Sourcing

Unlike earlier periods, presently evaluation of suppliers is done in the context of the supply chain (efficiency, flow, integration, responsiveness and customer satisfaction) which involves measures important at the strategic, operational and tactical level. **Strategic level** measures include **lead time against industry norm**, **Quality level, Cost saving initiatives, and supplier pricing against market**. Tactical level measures include the **efficiency of purchase order cycle time, booking in procedures, cash flow, quality assurance methodology and capacity flexibility.** Operational level measures include **ability in day to day technical representation, adherence to developed schedule, ability to avoid complaints and achievement of defect free deliveries**.

2.8.1.3 Make/Assemble

This stage/activity is very important as their performance has a major impact on product cost, quality, speed of delivery and delivery reliability, and flexibility. As it is quite an important part of the supply chain, production needs to be measured and continuously improved. Suitable measures for the production are as follows: **range of product and services, capacity utilization and effectiveness of scheduling techniques**

2.8.1.4 Delivery/Customer

In a supply chain, the link that directly impacts customers is delivery. It is a primary determinant of customer satisfaction; hence, measuring and improving delivery is always desirable to increase competitiveness. Measures for delivery performance evaluation are i**) number of faultless notes invoiced (an invoice shows the delivery date, time and condition under which goods were received ii) Flexibility of delivery systems to meet particular customer needs**. Another important measure under delivery is **total distribution cost**

2.8.1.5 Measuring customer service and satisfaction:

To assess supply chain performance, supply chain metrics must centre on customer satisfaction. **"Flexibility"** is one of the factors by which supply chains compete and can be rightly regarded as a critical one. Being flexible means having the capability to provide products/services that meet the individual demands of customers. Some flexibility measures include: (i) product development cycle time, (ii) machine/toolset up time, (iii) economies of scope -refers to the production of small quantities of wider range (e.g. JIT lot size) and (iv) number of Inventory turns**.** "**Customer query time"** is another important measure which relates to the time a firm takes to respond to a customer query with the required information. "**Post transaction measures of customer service**" is next important measure. The function of a supply chain does not end when goods are provided to the customer. Post transaction activities play an important role in customer service and provide valuable feedback that can be used to further improve supply chain performance.

2.8.1.6 Supply chain and Logistics cost:

The efficiency of a supply chain can be assessed using the total logistics cost—a financial measure. It is necessary to assess the financial impact of broad level strategies and practices that contribute to the flow of products in a supply chain. Since logistics cut across functional boundaries, care must be taken to assess the impact of actions to influence costs in one area in terms of their impact on costs associated with other areas (Cavinato, 1992). For example, a change in capacity has a major effect on cost associated with inventory and order processing. Some of the measures under this category are i) **Cost associated with assets and return on investment and ii) Information processing cost**

2.8.2 Performance measuring tools

As mentioned in the beginning of the section1.3.6, the most popular supply chain performance measuring tools are detailed as follows (Agami et al., 2012). '**Financial accounting'** is the traditional, regularly used tool as a part of any firm's fund flow operations and mostly concerned for all the firms as it measures costs attributable to different areas of operations or elements and finally measures the total cost/profit. This tool is still a very useful one as its output (cost/profit) provides a clear picture regarding the areas to be improved or the percentage of improvement obtained in different areas of business which will help the supply chain practitioners to take appropriate decisions accordingly for further improvement.

2.8.2.1 The Activity-Based Costing (ABC)

This approach was developed in 1987 by Kaplan and Bruns (1987) in attempt to tie financial measures to operational performance. It involves breaking down activities into individual tasks or cost drivers while estimating the resources, such as time and costs, needed for each one. Costs are then allocated based on these cost drivers rather than on traditional cost accounting methods such as allocating overhead either equally or based on less relevant cost drivers. The approach was designed in such a way to allow for better assessment of the true productivity and costs of a supply chain process. However, it still suffered the major limitation of relying only on pure financial metrics.

2.8.2.2 The Economic Value Analysis (EVA)

EVA is an approach developed in 1995 by Stern et al. (1995) for estimating a company's return on capital or economic value added. EVA approach is based on the premise that the shareholder's value is increased when a company earns more than its cost of capital. The EVA measure attempts to quantify the value created by an enterprise basing it on operating profits in excess of capital employed (through debt and equity). Though useful for assessing high level executive contributions and long-term shareholder value, EVA metrics fail to reflect operating supply chain performance since it only considers pure financial indicators.

2.8.2.3 Supply Chain Balanced Scorecard (SCBS)

SCBS was introduced by Kaplan and Norton in1992 as an indispensible performance management tool. It enables managers to observe a balanced view of both operational and financial measures at a glance. The authors proposed four basic perspectives that managers should monitor as follows: Financial (e.g., cost of manufacturing and cost of warehousing), Customer (e.g., on-time delivery and order fill rate), Internal Business Processes (e.g., manufacturing adherence-to-plan and forecast errors) and Innovation and Learning perspectives (e.g.,APICS-certified employees and new product development cycle time). Bearing these four perspectives in mind, managers can translate strategies into specific measures that can monitor the overall impact of a strategy on the enterprise. The goals and measures in each perspective are extracted from the enterprise strategy. Brewer and Speh (2000) demonstrate how a supply chain management framework is linked to the balanced scorecard. Even though SCBS is powerful tool, it suffers two basic limitations i) it is not participative and might fail to detect existing interactions between different process metrics. ii) It gives a frame work only and lacks an implementation methodology and thus deviates from the merit of concept itself.

2.8.2.4 Supply Chain Operations Reference (SCOR)

SCOR was created by the Supply Chain Council (Stephens, 2001; Huang et al., 2004; Lockamy and McCormack, 2004). This model defines a supply chain as being composed of five main integrated processes: Plan, Source, Make, Deliver and Return. Performance of most processes is measured from 5 perspectives: Reliability, Responsiveness, Flexibility, Cost and Asset. As the model spans the chain from supplier's supplier to customer's customer aligned with operational strategy, material, work and information flows, it is considered an exhaustive system that requires a well defined infrastructure, fully dedicated managerial resources and continuous business process re-engineering to align the business with best practices. The SCOR model framework can be found in Huang et al. (2004).

2.8.2.5 Logistics Scoreboard

It is a also a performance measuring tool in which recommended performance measures focus only on logistical aspects of the supply chain (Lapide, 2000). They fall into the following general categories: logistics financial performance measures (e.g., expenses and return on assets), logistics productivity measures (e.g., orders shipped per hour), logistics quality measures (e.g., shipment damage) and logistics cycle time measures (e.g., order entry time).

In our study, we have used Supply chain cost/profit for measuring and analysing the performance of supply chain. The reason for the selection is that firms are mostly concerned with supply chain profit/cost as it reflects the performance of the supply chain operations in totality as it is an overall performance measure. The mechanisms selected for study are those which have direct impact on costs and hence a financial performance measure was thought to be most appropriate. Hence the overall performance measure "supply chain profit/Cost" has been taken in this study.

Chapter 3

PERFORMANCE OF THREE LEVEL SUPPLY CHAIN WHILE USING PRICE DISCOUNT AND DELAY IN PAYMENT JOINTLY USING MATHEMATICAL MODELLING

Contents

3.1 Introduction

Coordination is essential to improve the performance of the Supply Chain (SC) as it involves multiple organisations and numerous activities with different policies led by different people. This creates interesting challenges for effective SC coordination. Long term effective coordination is possible by implementing proper coordination mechanisms based on the nature of the SC. Literature in the area of Supply Chain Management (SCM) shows that increasing importance is being given now to coordination in SCM to improve performance. Two popular coordination mechanisms in use are ‘price discount’ and ‘delay in payment’. The effect of these two mechanisms individually on SC performance has already been reported in literature as follows. Jaber et al (2006[a]) conducted a study using price discount as mechanism in a three level supply chain and Jaber et al (2006[b]) conducted a study using delay in payments as coordination mechanisms in a two level supply chain. In both the studies, they found out the improvement in performance due to coordination compared to ‘no coordination’. In this part of the study, we have considered a three level supply chain with combination of these mechanisms (price discount and delay in payment) simultaneously and found further significant improvement in the performance compared to individual cases of coordination. We have further extended this study to network supply chain under different business situations and it is presented in the chapter 4.

We have also conducted a sensitivity analysis to study the effect of changes in system parameters (rate of return, order quantity in various combinations and price elasticity of demand) on the output which will be useful for the supply chain practitioners to take appropriate decisions in the concerned area.

As mentioned above, in this part of the study, the two mechanisms ‘price discount’ and ‘delay in payment’ are used simultaneously to coordinate a three level SC. ‘Price discount’ is a coordination mechanism by which the seller provides a discount to the buyer to enhance the price elastic/ price dependent demand thereby coordinating the order quantity among the SC levels. ‘Delay in payment’ is another coordination mechanism by which the seller permits a delay in payment to the buyer for which the buyer need not pay any interest to the seller on the amount to be paid. But, the buyer can avail more time than is permitted for which the buyer has to pay interest on the amount to be paid for the additional period that exceeds the permitted one. Owing to the delay in payment, the buyer’s order quantity will be enhanced because of the reduction in holding cost. So, allowing ‘delay in payment’ also coordinates the order quantity among the SC levels. The details of benefit of simultaneous implementation of ‘price discount and delay in payment’ are explained in succeeding sections.

In this study, end customer demand is assumed as price elastic. So, the end customer demand increases as price decreases and hence the phenomenon of bullwhip effect will not occur. Further, as delay in payment is provided, the holding cost will be reduced. In mathematical modelling, annual demand rate is measured from the end side of the supply chain which is assumed to be a linear function of the discount rate given by the retailer.

In addition to the benefits of simultaneous use of ‘price discount and delay in payment’, the analysis of the effect of various system parameters on SC profit are also analysed in this part of the study which enables the SC practitioners to exercise appropriate control on the decision variables of the SC system. The SC profit (surplus) is taken as the performance measure in this study. The improvement in SC profit due to combination of ‘price discount and delay in payment’ is compared with the case of no coordination and price discount alone and the improvements reported.

3.2 Mathematical Modeling

The three level SC used in this study consists of one supplier, one manufacturer and one retailer as shown in Figure 1. In this case, annual customer demand is known and retailer places the order according to its Economic Order Quantity (EOQ). As the demand is assumed to be price elastic, the retailer provides an optimal discount to the customer to increase the demand. Similarly, each player provides optimal discount to their buyer in the SC to increase the demand and thereby the order quantity. At the same time, the supplier and the manufacturer allow delay in payment to their buyers due to which the holding cost of manufacturer and retailer decreases thereby increasing their order quantity. With permissible delay in payment, the retailer and the manufacturer have the opportunity to invest the unpaid balance for the period of delay in payment. The overall objective of implementation of these mechanisms (price discount and delay in payment) simultaneously is to enhance the volume of business and to improve the coordination among the SC members thereby improving the SC profit. Figure 3.1 shows the structure of the three-level SC and the strategic coordination mechanisms being implemented.

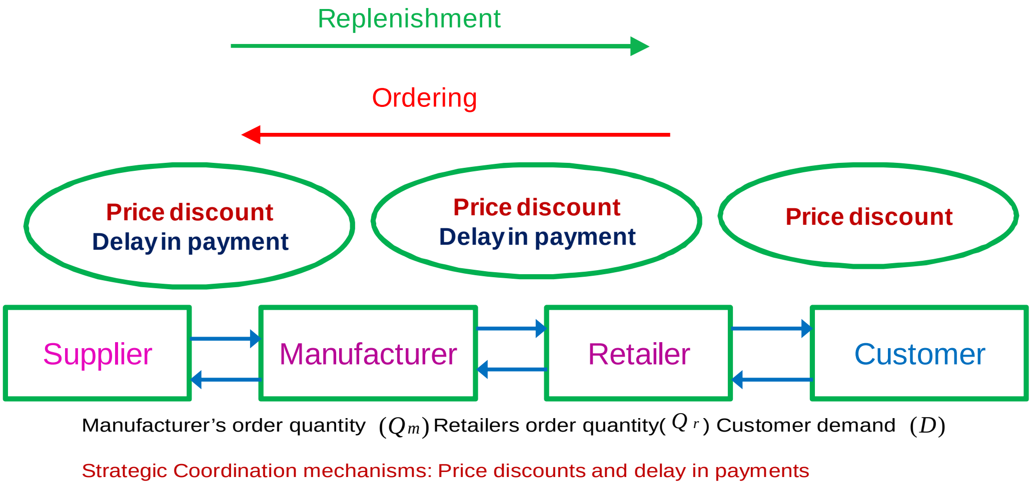

Figure 3.1: Structure of the Supply Chain

The work presented in this chapter deals with the modelling and analysis of a three level SC coordination with price discount along with delay in payment as mechanisms. The type of price discount used is 'all unit price discounts'. With the all-units price discount, discount will be given to all items in a given purchase quantity irrespective of the quantity purchased. The performance is measured by taking the sum of the profits of the three players in the SC. In this case, both the 'all unit price discount' and 'delay in payment' are used to coordinate the order quantities among the SC levels.

In this chapter, the section 3.2 is for mathematical modelling of the three level SC profit function. Sub section 3.2.1 present assumptions, 3.2.2 presents notations used in this modelling and subsection 3.2.3 present analysis part of the profit functions of each player in the three-level SC. Under subsection 3.2.3, subsections 3.2.3.1 to 3.2.3.3 present individual profit functions for the retailer, manufacturer and supplier respectively. Then, sub section 3.2.3.4 present the mathematical profit model for the three level SC with coordination using price discount along with delay in payment as coordination mechanisms. The model developed is a nonlinear mathematical model and this model approach is adopted as the operating conditions such as demand lead time etc are assumed to be static and known with certainty. Finally Section 3.3 presents numerical results; section 3.4 presents sensitivity analysis and section 3.5 presents conclusion.

3.2.1 Assumptions

This study used an SC consisting of a single supplier, single manufacturer and single retailer and considered the case of a single product. It is also assumed that no shortages are allowed at any level of the SC. Apart from this, zero lead time or instantaneous replenishment is assumed throughout the SC. Price elastic or price dependent demand is another important assumption in this study. Other relevant assumptions include the one like products have perfect quality, no rejections at any level of SC, instantaneous replenishment on placing the order, infinite planning horizon and cost parameters do not vary over time. As far as fund flow is concerned, it is also assumed that each player is financially capable of settling his/her balance with the preceding player at any point in time in a single payment. Linear storage cost per unit time is taken for the computations. In addition to this, 10% rate of return indicates recession, 15% rate of return indicates normal and 20% rate of return indicates boom situation in this study. Continuous compounding rate of return is assumed in this regard. This study also assumed that discount given by each player to its downstream player is 'all unit price discount' and supplier is not getting any delay in payment or price discount from its upstream player which is not considered as a part of this study.

With respect to inventory carrying cost, both holding cost and storage cost are considered in this study. Holding cost in this study is taken as cost due to interest on working capital and storage cost means all other costs incurred for storing (other costs such as rent, product deterioration and obsolescence, insurance etc) the item. Carrying cost can be taken as the sum of storage cost and holding cost. We have made this division of Carrying cost to calculate the effect of delay in payment. Holding cost is zero for the buyer till he makes the payment to the seller. However, seller incurs an additional holding cost till he gets the payment from the buyer even though the items are reached at buyer end. More details are given in the succeeding sections.

3.2.2 Notations

i = a subscript identifying a specific player in a supply chain; $i = s, m, r$

(s = supplier, m = manufacturer, r = retailer)

A_i = Order cost for player i, h_i = holding cost for player i , s_i = Storage cost for player i

c_i = Procurement cost for player i ,

k_i = Return on investment / interest to be paid for player i .

Actual end customer demand $D = D_0 + D_1 \times d_r$, Where D_0 = Initial demand, D_1 = Price elasticity of demand, d_r = Discount given by the retailer

p_i = Selling price for each player i

t_{ij} = Interest free permissible delay in payment period permitted by player i ' to player 'j' = t_{sm} & t_{mr}

τ_{ji} = Maximum possible delay in payment period availed by player ' j ' from player ' i ' = τ_{rm} & τ_{ms}, If $\tau_{ji} > t_{ij}$, the player i 'charges interest on player j for the period of $\tau_{ji} - t_{ij}$, Where $i \neq j$

Q_i =Quantity ordered by player $i = s, m, .r$

T_i = Inventory cycle time for player ' i ', $T_r = \frac{Q_r}{D}$, $T_m = \frac{\lambda_m \times Q_r}{D}$,

$$T_s = \frac{\lambda_m \times \lambda_s \times Q_r}{D}$$

λ_i = An integer lot sizing multiplier which when multiplied with the orders received at a supply chain stage/level gives the order quantity to be placed with the immediate up stream level means an integer multiplier to set the order quantity of player i ' to that of player ' j ' where $i \neq j$ and $\lambda_i = 1, 2, 3......$

For example, $Q_m = \lambda_m \times Q_r$ and $Q_s = \lambda_s \times Q_m = \lambda_s \times \lambda_m \times Q_r$

3.2.3 Analysis

Using the model developed and explained in the previous section, analysis has been carried out here. First, the profit functions of each of the three players are derived and this is then used to formulate the profit function for the SC. The effect of the two coordination mechanisms used has been incorporated in the profit function calculations which are given below.

3.2.3.1 Profit Function for Retailer

In this study, the retailer places his/her Economic Order Quantity (EOQ)

Q_r with the manufacturer who provides an optimal discount (d_m) to the retailer up to a maximum of the difference between his/her purchase cost and selling price. Similarly, the retailer also provides a discount (d_r) to his/her customers to enhance the end customer demand as it is price elastic/price dependent. Since the end customer demand increases, the retailer's EOQ also increases. Apart from this, the manufacturer allows the retailer a delay (t_{mr}) to make the payment up to a maximum of retailer's inventory cycle time for which retailer need not pay any interest on the amount of purchase cost to be paid to the manufacturer. At the same time, the retailer can also extend this permitted period but the retailer has to pay the interest (k_m) for the additional period that exceeds the permitted one. Owing to this delay in payment, the retailer's holding cost will be reduced and hence its EOQ further increases. The difference between sales revenue earned by the retailer, $Q_r p_r$ and the net cost for the retailer gives the profit (surplus) of the retailer.

Figure 3.2 illustrates the retailer's inventory cycle. As the demand is linear throughout the cycle, the average inventory per cycle is equal to $\frac{1}{2} \times Q_r \times T_r$. The holding cost per cycle is computed by multiplying the average inventory per cycle with holding cost h_r. So, the holding cost is $\frac{h_r Q_r^{\,2}}{2D}$. This being the case, it is assumed that delay in payment is possible in three ways. The first one is that permitted interest free delay in payment period for the retailer by the manufacturer, t_{mr} is less than or equal to retailer's(buyer) inventory cycle time, T_r and no more extension is allowed after permitted delay in payment period. In the second case, extension is allowed but interest has to be paid for the period after the permitted period till the payment is made. This allowable extended delay in payments τ_{rm} with interest can be less than or equal to the retailer inventory cycle time T_r . In the third case also, extension is possible by paying interest to the manufacturer for the period after the permitted period till the payment is done and the allowable extended delay in payments τ_{rm} with interest can be greater than or equal to retailer's inventory cycle time, T_r . In the second and third cases, the interest free permitted delay in payment period is less than or equal to retailer's inventory cycle time T_r as in first case. The retailer must pay the purchase cost, $c_r Q_r$, with the manufacturer either by the time t_{mr} or by time τ_{rm} . Thus, if the retailer avails delay in payment, retailer's holding cost per cycle is reduced from $\frac{h_r Q_r^{\ 2}}{2D}$ to either $\frac{h_r (Q_r - D \times t_{mr})^2}{2D}$ (case 1) or $\frac{h_r (Q_r - D \times \tau_{rm})^2}{2D}$ (case2) or 'Zero' (case3). The holding cost is zero for the case 3 as the payment is done by the retailer to manufacturer only after the retailer's inventory cycle time. The retailer incurs storage cost per cycle as $\frac{s_r Q_r^{\ 2}}{2D}$.

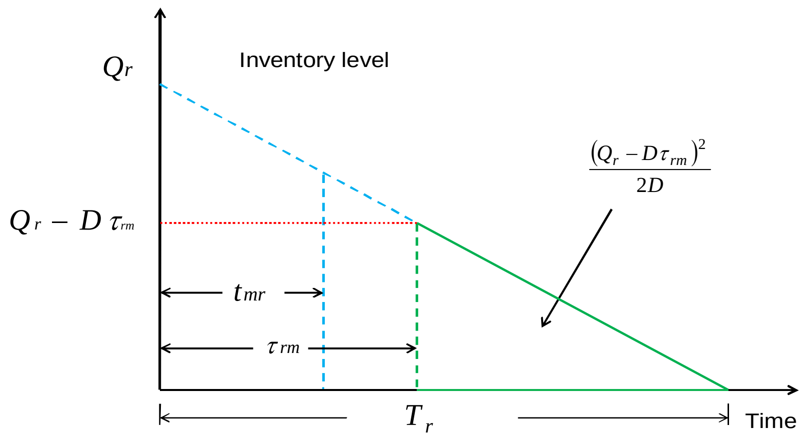

Figure 3.2: Illustrates the behavior of inventory in a retailer's cycle (modified from Jaber et al, 2006[b])

The delay in payment offered by the manufacturer provides the retailer an opportunity to invest the unpaid purchase cost $c_r Q_r$, for a period t_{mr} at a return rate of k_r. It is advantageous for the retailer to extend the delay in payment to maximum possible (τ_{rm}) if the return rate for the retailer exceeds that for the manufacturer $(k_r > k_m)$. As mentioned earlier, continuous compounding rate of return is assumed in this study. So, the term $c_r \times Q_r \times \{e^{(k_m \times (\tau_{rm} - t_{mr}))} - e^{(k_r \times \tau_{rm})}\}$ indicates the savings or additional cost for the retailer from investing an amount of $c_r Q_r$ for a period of length $\tau_{rm} (\tau_{rm} > t_{mr})$.

The term $c_r \times Q_r \times \{e^{(k_m \times (\tau_{rm} - t_{mr}))} - e^{(k_r \times \tau_{rm})}\}$ can be described as follows. If the retailer avails delay in payment from the manufacturer to a period τ_{rm} that exceeds the permitted interest-free period t_{mr}, then the retailer has to pay the interest along with the purchase cost of $c_r Q_r$ at a rate of k_m, for the period of $\tau_{rm} - t_{mr}$. At the same time, the retailer can invest this amount of purchase cost $(c_r Q_r)$ at a rate of k_r for a period τ_{rm}, and can earn some additional revenue equal to $c_r \times Q_r \times e^{(k_r \times \tau_{rm})}$.

Profit of the retailer = Sales revenue – Net cost 3(1)

Net cost per unit cycle = $\psi_r(Q_r, d_r, t_{mr}, \tau_{rm}, d_m)$

= order cost + procurement cost + storage cost + holding cost + Interest paid to manufacturer + discount to customer – (discount from manufacturer+ savings from investment) 3(2)

Quantity ordered by the retailer $= Q_r$

Discount offered by the retailer to the customer $= d_r$

Total Discount $= d_r \times Q_r$ 3(3)

Order cost = A_r

Procurement cost = $c_r \times Q_r$ 3(4)

Storage cost = $\dfrac{s_r \times (Q_r)^2}{2D}$ 3(5)

Holding cost = $H_r(Q_r, t_{mr}, \tau_{rm})$

$= \dfrac{h_r(Q_r - D \times t_{mr})^2}{2D}$ (case1) or $\dfrac{h_r(Q_r - (D \times \tau_{rm}))^2}{2D}$ (case2) or ‘Zero’ (case3) 3(6)

Inventory cycle time for retailer $T_r = \dfrac{Q_r}{D}$ 3(7)

Discount by manufacturer = $d_m \times Q_r$ 3(8)

Interest paid to manufacturer = $c_r \times Q_r \times e^{(k_m \times (\tau_{rm} - t_{mr}))}$ 3(9)

Savings from the investments = $c_r \times Q_r \times e^{(k_r \times \tau_{rm})}$ 3(10)

Net cost of retailer per cycle = $\psi_r(Q_r, d_r, t_{mr}, \tau_{rm}, d_m)$

$$\psi_r(Q_r, d_r, t_{mr}, \tau_{rm}, d_m) = A_r + (c_r \times Q_r) + (\frac{s_r \times Q_r^2}{2D}) + H_r(Q_r, t_{mr}, \tau_{rm})$$
$$+(d_r \times Q_r) - (d_m \times Q_r) + c_r \times Q_r \times \{e^{(k_m \times (\tau_{rm} - t_{mr}))} - e^{(k_r \times \tau_{rm})}\} \quad 3(11)$$

Net cost of retailer per unit time = $\dfrac{\psi_r(Q_r, d_r, t_{mr}, \tau_{rm}, d_m)}{T_r}$

$$= \frac{A_r \times D}{Q_r} + (c_r \times D) + \frac{s_r \times Q_r^2}{2}$$

$$+ \frac{D \times H_r(Q_r, t_{mr}, \tau_{rm})}{Q_r} + d_r \times D - d_m \times D$$
$$+ c_r \times D \times \{e^{(k_m \times (\tau_{rm} - t_{mr}))} - e^{(k_r \times \tau_{rm})}\} \quad 3(12)$$

Sales revenue per cycle = $Q_r \times p_r$ 3(13)

Sales revenue per unit time = $\dfrac{Q_r \times p_r}{T_r} = \dfrac{Q_r \times p_r \times D}{Q_r} = p_r \times D$ 3(14)

Net Profit for the retailer per unit time= Sales revenue per unit time – Net cost per unit time

$$= P_{ret}(Q_r, d_r, \tau_{rm}, t_{mr}, d_m) = (p_r \times D) - [\frac{A_r \times D}{Q_r} + (c_r \times D) + (\frac{s_r \times Q_r}{2})$$
$$+ \frac{D \times H_r(Q_r, t_{mr}, \tau_{rm})}{Q_r} + d_r \times D - d_m \times D$$
$$+ c_r \times D \times \{e^{k_m \times (\tau_{rm} - t_{mr})} - e^{(k_r \times \tau_{rm})}\}] \quad 3(15)$$

3.2.3.2 Profit Function for Manufacturer

In this case, manufacturer places an optimal order quantity $(\lambda_m Q_r)$ with the supplier and dispatches shipments of Q_r units to the retailer. It is to be noted that the replenishment is assumed as instantaneous between any two players in this study. That means the manufacturer replenishes his/her inventory instantaneously in every cycle time $(T_m = \frac{\lambda_m Q_r}{D})$. Once the shipment from the supplier reaches the manufacturer, he/she instantaneously delivers the first shipment to the retailer and thereafter his/her every inventory cycle time $(T_r = \frac{Q_r}{D})$. As the retailer gets the delay in payment and price discount from the manufacturer, the manufacturer also gets a price discount (d_s) as well as delay in payment (t_{sm} or τ_{ms}) from the supplier for the purchase cost. The limit for the maximum discount is the difference between respective player's purchase cost and selling price and for the permitted interest free delay in payment, the maximum limit is manufacturer's (buyer's) inventory cycle time. Owing to the permitted delay in payment provided by the manufacturer to the retailer, manufacturer will lose the opportunity to invest its profit per order over this permitted delay in payment period and this opportunity cost is equal to $(c_r - c_m) \times \lambda_m \times Q_r \times e^{(k_m \times t_{mr})}$, where it is assumed that the manufacturer pays its total purchase cost $(c_m \times \lambda_m \times Q_r)$ at the beginning of its inventory cycle. As explained earlier, if the retailer avails the delay in payment that exceeds the permitted $(\tau_{rm} > t_{mr})$, then the manufacturer will get the interest for the purchase cost amount to be obtained from the retailer at the rate of k_m , for a period of $(\tau_{rm} - t_{mr})$.

Apart from all the above cots, unlike the retailer, the manufacturer incurs an additional holding cost. This is due to the fact that even though the shipment reaches the retailer, his/her financial burden is carried by the manufacturer till he/she gets the payment of purchase cost from the retailer by the time either by t_{mr} or τ_{rm}. This additional cost is computed by multiplying the shaded area $(Q_r \times \tau_{rm})$ in Figure 3.3 by the manufacturer's holding cost. Since it occurs λ_m times in every manufacturer's cycle, the total additional holding cost incurred by the manufacturer in each cycle is $(h_s \times Q_r \times \tau_{rm} \times \lambda_m)$.

Figure 3.3 depicts the behavior of inventory level of retailer and manufacturer for a typical supply chain system for $\lambda_m = 4$

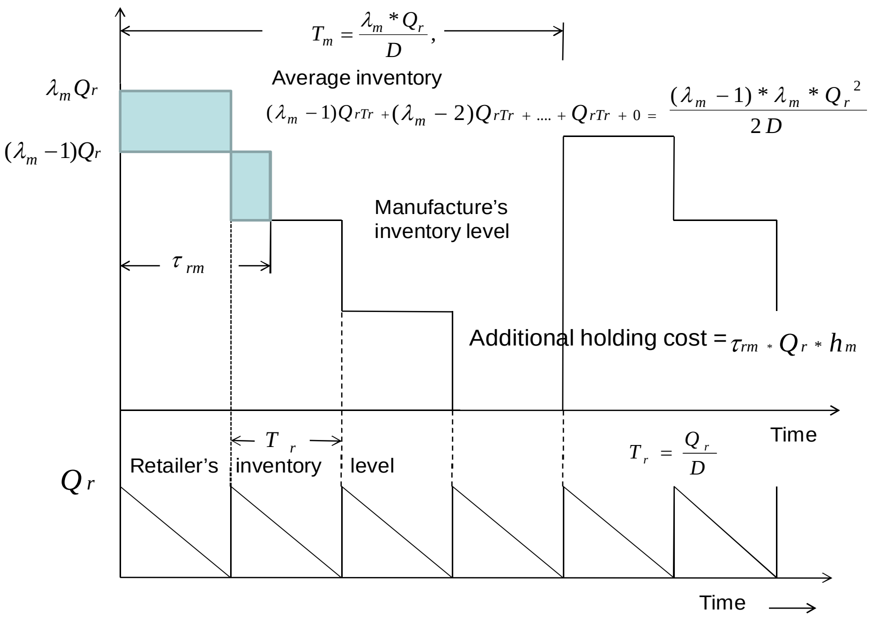

Figure 3.3: Illustrates the behavior of inventory levels for the retailer and manufacturer of a supply chain (Modified from Jaber et al, 2006[b])

As far as delay in payments is concerned, three cases can happen between manufacturer and supplier as in the case of retailer and manufacturer (discussed in section 3.2.3.1). The manufacturer must settle his/her purchase cost, $c_m \lambda_m Q_r$ with the supplier either by the time t_{sm} or by time τ_{ms}, thus manufacturer's holding cost per cycle is reduced from $\frac{h_m(\lambda_m \times Q_r)^2}{2D}$ to either $\frac{h_m(\lambda_m \times Q_r - D \times t_{ms})^2}{2D}$ (case 1) or $\frac{h_m(\lambda_m \times Q_r - D \times \tau_{ms})^2}{2D}$ (case 2) or 'Zero' (case3) . The holding cost is zero for the case 3 as the payment is made by the manufacturer to the supplier only after the manufacturer's inventory cycle time. The manufacturer incurs storage cost per cycle as $\frac{s_m \times (\lambda_m - 1) \times \lambda_m \times Q_r^{\ 2}}{2D}$.

The delay in payment offered by the supplier provides an opportunity to the manufacturer to invest the unpaid balance $c_m \lambda_m Q_r$, for a period t_{sm} at a return rate of k_m. It is advantageous for the manufacturer to extend the delay in payment to the maximum possible (τ_{ms}) if the return rate for the manufacturer exceeds that for the supplier $(k_m > k_s)$. As mentioned earlier, continuous compounding rate of return is assumed in this study. So, the term $c_m \times \lambda_m \times Q_r \times \{e^{(k_s \times (\tau_{ms} - t_{sm}))} - e^{k_m \times \tau_{ms}}\}$ indicates the savings or additional cost form investing an amount of $c_m \lambda_m Q_r$ for a period of $\tau_{ms} (\tau_{ms} > t_{sm})$.

The term $c_m \times \lambda_m \times Q_r \times \{e^{(k_s \times (\tau_{ms} - t_{sm}))} - e^{k_m \times \tau_{ms}}\}$ can be described as follows. If the manufacturer avails its delay in payment from the supplier to a period τ_{ms} that exceeds the interest-free period t_{sm}, then the manufacturer has to pay the interest along with the purchase cost of $(c_m \lambda_m Q_r)$ at a rate of k_s, for the period $\tau_{ms} - t_{sm}$. At the same time, the manufacturer can invest this amount of purchase cost at the rate of k_m for a period of τ_{ms} and can earn some additional revenue equal to $c_m \times \lambda_m \times Q_r \times e^{(k_s \times (\tau_{ms} - t_{sm}))}$ as in the case of retailer.

Profit of manufacturer = Sales revenue – Net cost 3(16)

Net cost per unit cycle = $\psi_m (Q_r, d_r, d_m, d_s, \tau_{ms}, t_{sm}, \lambda_m)$

= Order cost + Procurement cost + Storage cost + Holding cost + Interest paid to supplier + Cost due to loss of opportunity to invest the profit + Discount to retailer – (savings from investment+ Interest paid by retailer + Discount by supplier). 3(17)

Discount rate by manufacturer to retailer = d_m

Quantity ordered by the manufacturer = $Q_m = \lambda_m \times Q_r$ 3(18)

Discount by supplier = $d_m \times Q_m = d_m \times \lambda_m \times Q_r$ 3(19)

Storage cost $= s_m \dfrac{\sum_{n=1}^{\lambda_m} (\lambda_m - n) Q_r^2}{2D} =$

$$\frac{s_m \times (\lambda_m - 1) \times \lambda_m \times Q_r^{\ 2}}{2D} \qquad 3(20)$$

Holding cost = $H_m(Q_m, t_{sm}, \tau_{ms}) = \frac{h_m\left(\lambda_m \times Q_r - D \times t_{ms}\right)^2}{2D}$ (Case1),

Or $\frac{h_m \times ((\lambda_m \times Q_r) - (D \times \tau_{ms}))^2}{2D}$ (Case 2), Or 'Zero' (Case3) 3(21)

Additional holding cost $= h_m Q_r \lambda_m \tau_{rm}$ 3(22)

Inventory cycle time for manufacturer $= T_m = \frac{\lambda_m \times Q_r}{D}$ 3(23)

Procurement cost $= c_m \times \lambda_m \times Q_r$ 3(24)

Interest paid to supplier $= c_m \times \lambda_m \times Q_r \times e^{(k_s \times (\tau_{ms} - t_{sm}))}$ 3(25)

Savings from investment $= c_m \times \lambda_m \times Q_r \times e^{(k_m \times \tau_{ms})}$ 3(26)

Interest paid by retailer $= c_r \times Q_r \times e^{(k_m \times (\tau_{rm} - t_{mr}))}$ 3(27)

Cost due to loss of opportunity to invest the profit $= (c_r - c_m) \times \lambda_m \times Q_r \times e^{(k_m \times t_{mr})}$ 3(28)

Cost function per unit cycle $= \psi_m(Q_r, d_r, d_m, d_s, \tau_{ms}, \tau_{rm}, t_{sm}, t_{mr}, \lambda_m)$

$$= A_m + (c_m \times \lambda_m \times Q_r) + \frac{s_m \times (\lambda_m - 1) \times \lambda_m \times Q_r^{\ 2}}{2D}$$

$$+H_m(Q_r,\lambda_m,t_{sm},\tau_{ms})+c_m\times\lambda_m\times Q_r\times e^{(k_s\times(\tau_{ms}-t_{sm}))}$$

$$+c_m\times\lambda_m\times Q_r\times e^{(k_m\times\tau_{ms})}-c_r\times Q_r\times e^{(k_m\times(\tau_{rm}-t_{mr}))}$$

$$+(c_r-c_m)\times\lambda_m\times Q_r\times e^{(k_m\times t_{mr})}+h_m Q_r\lambda_m\tau_{rm}$$

$$-d_s\times\lambda_m\times Q_r+d_m\times\lambda_m\times Q_r$$

3(29)

Cost function per unit time

$$=\frac{\Psi_m}{T_m}=\frac{A_m\times D}{\lambda_m\times Q_r}+c_m\times D+\frac{s_m\times(\lambda_m-1)\times Q_r}{2}$$

$$+\frac{D\times H_m(Q_r,\lambda_m,t_{sm},\tau_{ms})}{\lambda_m\times Q_r}+c_m\times D\times e^{(k_s\times(\tau_{ms}-t_{sm}))}$$

$$-c_m\times D\times e^{(k_m\times\tau_{ms})}-d_s\times D+d_m\times D+h_m\times\tau_{rm}\times D$$

$$-\frac{c_r\times D\times e^{(k_m\times(\tau_{rm}-t_{mr}))}}{\lambda_m}+(c_r-c_m)\times D\times e^{(k_m\times t_{mr})}$$

3(30)

Sales revenue per unit cycle $=Q_r\times\lambda_m\times p_m$ 3(31)

Sales revenue per unit time $=\dfrac{Q_r\times\lambda_m\times p_m}{T_m}=p_m\times D$ 3(32)

Profit of manufacturer per unit time $=P_{mfr}(Q_r,d_m,d_s,\lambda_m,\tau_{ms},t_{sm})$

= Sales revenue per unit time –Net cost per unit time

$$= p_m \times D - [\frac{A_m \times D}{\lambda_m \times Q_r} + c_m \times D + \frac{s_m \times (\lambda_m - 1) \times Q_r}{2}$$

$$+ \frac{D \times H_m(Q_r, \lambda_m, t_{sm}, \tau_{ms})}{\lambda_m \times Q_r} + c_m \times D \times e^{(k_s \times (\tau_{ms} - t_{sm}))}$$

$$-c_m \times D \times e^{(k_m \times \tau_{ms})} - d_s \times D + d_m \times D + h_m \times \tau_{rm} \times D$$

$$-\frac{c_r \times D \times e^{(k_m \times (\tau_{rm} - t_{mr}))}}{\lambda_m} + (c_r - c_m) \times D \times e^{(k_m \times t_{mr})}] \quad 3(33)$$

3.2.3.3 Profit Function for Supplier

In this case, supplier places an optimal order quantity $(\lambda_m \lambda_s Q_r)$ on its upstream player (which is not a part of this study as such) and dispatches shipments of Q_m units to the manufacturer. As the replenishment is instantaneous in this study, the supplier replenishes his/her inventory instantaneously in every cycle time $(T_s = \frac{\lambda_m \lambda_s Q_r}{D})$. Once the shipment reaches the supplier, he/she instantaneously delivers the first shipment to the manufacturer and thereafter his/her every inventory cycle time $(T_m = \frac{Q_m}{D})$. Owing to the permitted delay in payment (t_{sm}) provided by the supplier to the manufacturer, the supplier will lose the opportunity to invest his/her profit per order over this permitted delay in payment period and this opportunity cost is equal to $(c_m - c_s) \times \lambda_m \times \lambda_s \times Q_r \times e^{(k_s \times t_{sm})}$, where it is assumed that the supplier pays his/her total purchase cost $(c_m \times \lambda_m \times \lambda_s \times Q_r)$ at the beginning of its inventory cycle. As explained earlier, if the manufacturer avails the delay in payment that exceeds the permitted $(\tau_{ms} > t_{sm})$, then the supplier will get the interest for the purchase cost amount to be obtained from the manufacturer at the rate of k_s, for a period of $(\tau_{ms} - t_{sm})$. As mentioned earlier, the supplier also provides a unit discount of d_s to the manufacturer but he/she does not get any discount from his/her upstream player in this study.

As discussed in the previous section of manufacturer's profit function, the supplier also incurs additional holding cost in this study due to the reason that the supplier provides the delay in payment even after the items reaching the manufacturer and carries the financial burden till manufacturer makes the payment. Since this cost is incurred λ_s times in a supplier's cycle, then the total additional holding cost incurred by the supplier in each cycle is $h_s Q_r \lambda_m \lambda_s \tau_{ms}$. This holding cost is different from the normal holding cost calculated earlier.

Profit of supplier = Sales revenue – Net cost

Net cost of supplier per unit cycle = Order cost + Procurement cost + Storage cost + Holding cost + Cost due to loss of opportunity to invest the profit + Discount to manufacturer- Interest paid by manufacturer 3(34)

Cost function per unit cycle $= \psi_s(Q_r, d_r, d_m, d_s, t_{sm}, \tau_{ms}, \lambda_m, \lambda_s)$

Discount rate by the supplier to the manufacturer $= d_s$

Quantity ordered by the supplier $= \lambda_m \times \lambda_s \times Q_r$ 3(35)

Discount to manufacturer $= d_s \times Q_s = d_s \times \lambda_m \times \lambda_s \times Q_r$ 3(36)

Procurement cost $= c_s \times \lambda_m \times \lambda_s \times Q_r$. 3(37)

Storage cost and holding cost $= \dfrac{(s_s + h_s)\sum_{n=1}^{\lambda_s}(\lambda_s - n)Q_r^2\lambda_m^2}{D}$

$$= \frac{(s_s + h_s)\times(\lambda_m \times Q_r)^2 \times \lambda_s \times (\lambda_s - 1)}{2D} \quad 3(38)$$

Additional holding cost $= h_s \times \lambda_m \times \lambda_s \times Q_r \times \tau_{ms}$ 3(39)

Inventory time of cycle for the supplier $= T_s = \dfrac{\lambda_m \times \lambda_s \times Q_r}{D}$ 3(40)

Interest paid by manufacturer $= c_m \times \lambda_m \times Q_r \times e^{(k_s \times (\tau_{ms} - t_{sm}))}$ 3(41)

Investment due to delay in payments

$$= (c_m - c_s)\times \lambda_m \times \lambda_s \times Q_r \times e^{(k_s \times t_{sm})} \quad 3(42)$$

Net Cost per unit cycle $= \psi_s(Q_r, d_r, d_m, d_s, t_{sm}, \tau_{ms}, \lambda_m, \lambda_s)$

$$= A_s + (c_s \times \lambda_m \times \lambda_s \times Q_r) + \frac{s_s \times (\lambda_m \times Q_r)^2 \times \lambda_s \times (\lambda_s - 1)}{2D}$$

$$+ \frac{h_s \times (\lambda_m \times Q_r)^2 \times \lambda_s \times (\lambda_s - 1)}{2D} + h_s \times \lambda_m \times \lambda_s \times Q_r \times \tau_{ms}$$

$$+ d_s \times \lambda_m \times \lambda_s \times Q_r - c_m \times \lambda_m \times Q_r \times e^{(k_s \times (\tau_{ms} - t_{sm}))}$$

$$+ (c_m - c_s)\times \lambda_m \times \lambda_s \times Q_r \times e^{(k_s \times t_{sm})} \quad 3(43)$$

Net cost per unit time = $\dfrac{\psi_s}{T_s}$

$$= \frac{A_s \times D}{\lambda_m \times Q_r \times \lambda_s} + (c_s \times D) + \frac{s_s \times Q_r \times \lambda_m \times (\lambda_s - 1)}{2}$$

$$+ \frac{h_s \times Q_r \times \lambda_m \times (\lambda_s - 1)}{2} + h_s \times \tau_{ms} \times D$$

$$- \frac{c_m \times D \times e^{(k_s \times (\tau_{ms} - t_{sm}))}}{\lambda_s} + d_s \times D$$

$$+(c_m - c_s) \times D \times e^{(k_s \times t_{sm})} \quad 3(44)$$

Sales revenue per unit cycle $= \lambda_m \times \lambda_s \times Q_r \times p_s$ 3(45)

Sales revenue per unit time $= \dfrac{\lambda_m \times \lambda_s \times Q_r \times p_s}{T_m} = p_s \times D$ 3(46)

Profit of supplier per unit time $= P_{\sup}(Q_r, d_r, d_m, d_s, \tau_{ms}, t_{sm}, \lambda_m, \lambda_s)$

= Sales revenue per unit time-Net cost per unit time

$$= p_s \times D - [\frac{A_s \times D}{\lambda_m \times Q_r \times \lambda_s} + (c_s \times D) + \frac{s_s \times Q_r \times \lambda_m \times (\lambda_s - 1)}{2}$$

$$+ \frac{h_s \times Q_r \times \lambda_m \times (\lambda_s - 1)}{2} + h_s \times \tau_{ms} \times D$$

$$- \frac{c_m \times D \times e^{(k_s \times (\tau_{ms} - t_{sm}))}}{\lambda_s} + d_s \times D + (c_m - c_s) \times D \times e^{(k_s \times t_{sm})}] \quad 3(47)$$

3.2.3.4 Total Supply Chain Profit Function

The total supply chain profit function (P_{sc}) with coordination (price discount and delay in payment simultaneously as mechanisms) can be taken as the sum of the profit functions of the retailer [equation 3(15)], manufacturer [equation 3(33)] and supplier [equation 3(47)] under the sections 3.2.3.1, 3.2.3.2 &3.2.3.3.respectively. With coordination, the retailer, manufacturer and supplier need to agree on the following decision variables Q_r, λ_m, λ_s, τ_{ms}, t_{sm} τ_{rm}, t_{mr}, d_r, d_m, d_s that maximizes the total SC profit. The decision variables and other parameters are defined as follows

Q_r = Order quantity of retailer

λ_m, λ_s = An integer lot size multiplier of manufacturer, supplier respectively

τ_{ms} = Delay in payment availed by manufacturer from supplier

τ_{rm} = Delay in payment availed by retailer from manufacturer

t_{mr} = Interest free delay in payment permitted by manufacturer to the retailer

t_{sm} = Interest free delay in payment permitted by supplier to the manufacturer

d_r, d_m, d_s = Discount given by the retailer, manufacturer, supplier respectively

p_r, p_m, p_s = Selling price of retailer, manufacturer, supplier respectively

c_r, c_m, c_s = Procurement cost of retailer, manufacturer, supplier respectively

The mathematical model could then be written as follows:

Maximize supply chain profit $P_{sc} = P_{ret} + P_{mfr} + P_{\sup}$ 3(48)

$P_{ret}, P_{mfr}, P_{\sup}$ = Profit functions of retailer, manufacturer, supplier respectively

Subject to the constraints:

$\lambda_m, \lambda_s \geq 1$ 3(48a), $Q_r \geq 1$ 3(48b), $\tau_{rm}, t_{mr}, \tau_{ms}, t_{sm} \geq 0$ 3(48c)

Maximum discount permitted:

$$d_s \leq p_s - c_s, d_m \leq p_m - (p_s - d_s), d_r \leq p_r - (p_m - d_m), \quad 3(48d)$$

Maximum delay in payment:

Case 1	Case 2	Case 3
$Q_r / D - t_{mr} \geq 0$ 3(48e) $\lambda_m Q_r / D - t_{sm} \geq 0$ (3(48f)	$Q_r / D - \tau_{rm} \geq 0$ 3(48g) $Q_r / D - t_{mr} \geq 0$ 3(48h) $\lambda_m Q_r / D - \tau_{ms} \geq 0$ 3(48i) $\lambda_m Q_r / D - t_{sm} \geq 0$ 3(48j) $\tau_{rm} \geq t_{mr}, \tau_{ms} \geq t_{sm}$ 3(48k)	$\tau_{rm} - Q_r / D \geq 0$ 3(48l) $t_{mr} - Q_r / D \leq 0$ 3(48m) $\tau_{ms} - \lambda_m Q_r / D \geq 0$ 3(48n) $t_{sm} - \lambda_m Q_r / D \leq 0$ 3(48o) $\tau_{rm} \geq t_{mr}, \tau_{ms} \geq t_{sm}$ 3(48p)

Equation 3(48) represents the SC profit maximization function. Constraint 3(48a) indicates that the integer lot sizing multiplier of manufacturer and supplier is greater than or equal to one and constraint 3(48b) indicates that the order quantity of retailer is greater than or equal to one. 3(48c) indicates that the delay in payment availed by the retailer from the manufacturer (τ_{rm}), the delay in payment permitted by the manufacturer to the retailer (t_{mr}), the delay in payment availed by manufacturer from the supplier (τ_{ms}) and the delay in payment permitted by the supplier to the manufacturer (t_{sm}) will be greater than or equal to zero. Constraint 3(48d) indicates that the discount given by each player must be less than or equal to the difference between his/her selling price and discounted unit purchase cost. Constraint 3(48e) indicates the delay in payment permitted by the manufacturer (t_{mr}) to the retailer is less than or equal to the retailer's inventory cycle time ($\frac{Q_r}{D}$). Constraint 3(48f) indicates that the delay in payment permitted by the supplier (t_{sm}) to the manufacturer is less than or equal to the manufacturer's inventory cycle time ($\frac{\lambda_m Q_r}{D}$). Constraint

3(48g) indicates that the delay in payment availed by the retailer from the manufacturer (τ_{rm}) is less than the retailer's inventory cycle time $(\frac{Q_r}{D})$. Constraint 3(48h) indicates that the delay in payment permitted by the manufacturer to the retailer (t_{mr}) is less than or equal to the retailer's inventory cycle time $(\frac{Q_r}{D})$. Constraint 3(48i) indicates that the delay in payment availed by the manufacturer from the suppler (τ_{ms}) is less than or equal to the manufacturer's inventory cycle time $(\frac{\lambda_m Q_r}{D})$. Constraint 3(48j) indicates that the delay in payment permitted by the supplier to the manufacturer (t_{sm}) is less than or equal to the manufacturer's inventory cycle time $(\frac{\lambda_m Q_r}{D})$. Constraint 3(48k) indicates that the delay in payment availed by the retailer from the manufacturer (τ_{rm}) is greater than or equal to delay in payment permitted by the manufacturer to the retailer (t_{mr}) and the delay in payment availed by the manufacturer from the supplier (τ_{ms}) is greater than or equal to the delay in payment permitted by the suppler to the manufacturer (t_{sm}). Constraint 3(48l) indicates that the delay in payment availed by the retailer from the manufacturer (τ_{rm}) is greater than or equal to retailer's inventory cycle time $(\frac{Q_r}{D})$. Constraint 3(48m) indicates that the delay in payment permitted by the manufacturer (t_{mr}) to the retailer is less than or equal to the retailer's inventory cycle time $(\frac{Q_r}{D})$. Constraint 3(48n) indicates that the delay in payment availed by the manufacturer from the supplier (τ_{ms}) is greater than or equal to manufacturer's inventory cycle time $(\frac{\lambda_m Q_r}{D})$. Constraint 3(48o) indicates that the delay in payment permitted by the supplier to the manufacturer (t_{sm}) is less than or equal to the manufacturer's inventory cycle time $(\frac{\lambda_m Q_r}{D})$. Constraint 3(48p) indicates that the delay in payment availed by the retailer from the manufacturer (τ_{rm}) is greater than or equal to delay in payment permitted by the manufacturer to the retailer (t_{mr}) and the delay in payment availed by the manufacturer from the supplier (τ_{ms}) is greater than or equal to the delay in payment permitted by the supplier to the manufacturer (t_{sm}).

As mentioned in the beginning, the price discounts and the delay in payments are effected in transactions between supplier & manufacturer and manufacturer & retailer. The retailer permits only price discount to the customer but no delay in payments. Under these circumstances, three cases are possible for delay in payments (case 1, 2, & 3 in the set of constraints given above) as explained below. Each case is considered separately for solving the above mathematical model and the results are compared and analyzed.

Case1 - The seller permits interest free permissible delay in payments to the buyer up to a maximum period of buyer's inventory cycle time and no extension of delay in payment is allowed after the permitted period.

Case 2 - The buyer can extend the delay in payment period even over the permitted interest free delay in payment period but maximum up to his/her inventory cycle time. That means, interest free delay in payment period will be less than or equal to delay in payment period with interest and both can be maximum up to buyer's inventory cycle time.

Case 3 - Delay in payments period can be extended even over the buyer's inventory cycle time. But, the maximum interest free delay in payment period is up to the buyer's inventory cycle time only as in above two cases.

3.3 Numerical Results

The nonlinear mathematical model developed for the three level supply chain coordination with case 1, case 2 and case 3 are solved using 'Excel solver'. This study shows that the profit is more for the case 3 and the same is used for the comparison with results obtained when using price discounts only as mechanism used by Jaber et al. (2006).

The table 3.1 consists of data adopted from Munson and Rosenblatt (2001) is used for analysis. It is assumed that a fixed annual demand of 150000 units and it increases with increase in discount offered by the retailer and the elasticity of demand. This means that the chain is driven by the retailer's annual sales volume. Thus, the actual demand (D) is equal to $D_0 + D_1 \times d_r$ where D_1 = 1000… 5000 … 10000…15000, etc. The return on investment (ROI) is taken as 15% per annum (normal state of the business) in all cases except in the sensitivity analysis of this SC system under different market conditions/ROI of each player. Unit time in this study is taken as a year.

Table 3.1: Munson and Rosenblatt's (2001) data set used for this study

Player	Set up cost (Rs)	Purchase cost (Rs)	Holding cost (Rs)	Storage Cost* (Rs)	Profit Margins (%)	Selling Price (Rs)	Return on Investment* (%)
Supplier	400	200	10	2	25	250.00	15
Manufacturer	200	250	12	3	25	312.50	15
Retailer	30	312.50	16	4	25	390.63	15

*added in this study

Table 3.2: Supply chain performance for the three cases of delay in payments along with price discounts (D_1 =1000, $k_r = 15\%$, $k_m = 15\%$, $k_s = 15\%$)

Case	λ_m	λ_s	t_{mr}	τ_{rm}	t_{sm}	τ_{ms}	d_r	d_m	d_s	Supply chain profit (Rs.)	Increase in profit (%) in case 2&3 (with base as case 1)
1	3	1	0.009	-	0.028	-	21.28	10.0	3.69	29107526	0
2	3	1	0.009	0.009	0	0.028	21.28	10.0	3.69	29143672	0.12
3	3	1	0.009	0.009	0	0.050	20.61	10.0	0	29250439	0.51

Table 3.2 shows the supply chain performance for the three cases of delay in payment along with price discount. This analysis shows that case 2 provides slightly more profit than case1 and case 3 provides significantly higher profit than case1 & 2. The reasons for this phenomenon are as follows. When the delay in payment is implemented along with price discount, the net inventory carrying cost decreases due to both the reduction in holding cost and the increase in end customer demand as the demand is price elastic. It further reduces in the third case in which the buyer can avail delay in payment more than its inventory cycle time (interest to be paid by the buyer to the seller for exceeding period than the permitted interest free period). Apart from this when the buyer gets more time than its inventory cycle time for the investment, the amount that is available for investment will be relatively more and the net savings for the third case will be also more than the first two cases. The optimal value of interest free delay in payment permitted by the supplier to the manufacturer is obtained as zero as supplier does not get any delay in payment from its upstream player in this study. In the first case, the delay in payment is not permitted more than buyer’s inventory cycle time. So, the net savings from its investment is very less compared to other two cases. In the second and third case, it is obtained that the optimal values of the (0.009) delay in payment permitted (without interest)is equal to the delay in payment (0.009)availed

(with interest) between retailer and manufacturer as both the parties have equal opportunities for investment with same rate of return. The optimal value of price discount is obtained as minimum (zero) for supplier and maximum (20.61) for retailer in the third case (maximum SC profit case). The reasons for these observations are supplier is not getting any discount from its upstream player and the discount given by the retailer decides the end customer demand respectively. So, the third case of delay in payment can be implemented to have maximum improvement in SC profit among these three cases considering all practical aspects.

Table 3.3: Profit comparison when using price discounts alone and along with 'delay in payments' Vs 'No coordination' ($D_1 = 1000$, $\lambda_m = 3$, $\lambda_s = 1$, $k_r = 15\%$, $k_m = 15\%$, $k_s = 15\%$)

Benefit when using price discounts alone and 'no coordination' (Jaber et al., 2006[a])			Profit under combination of mechanisms (Price discounts with delay in payments) (Case 3) (c)	Increase in profit (%) under combination of mechanisms (case3) compared to 'no coordination' ((c-a)/a)x100
SC Profit under no coordination (a)	SC profit under discount alone (b)	Increase in profit (%) under discount alone compared to no coordination ((b-a)/a)x100		
28538426	28950375	1.44	29250439	2.49

Table 3.3 shows the profit comparison while using 'price discount alone and along with delay in payment' versus 'no coordination'. The analysis shows the use of price discount along with delay in payment (case3) enhances the SC profit significantly and this hike in profit from price discount alone is approximately equal to the hike in profit between no coordination and price discount alone. So, this study suggests incorporating price discount along with delay in payment as strategic coordination mechanisms improve the SC performance than the case of price discount alone. So, this analysis also

relevant as it is useful to take appropriate decision on the implementation of coordination mechanism(s) considering the effort (cost aspects) required for the same. The increase in profit in the case of delay in payment is due to the decrease in inventory carrying cost and net saving from the investment due to the delay in payment. The increase in profit in the case of price discount is due to the increase in end customer demand as it is price elastic. The combined effect is reflected in the case of combination of both price discount and delay in payment.

3.4 Sensitivity Analysis

The effect of change in various parameters on SC performance is also analyzed to understand the sensitivity of this supply chain system and it will enable the decision maker to take proper decisions accordingly. The parameters considered for the sensitivity analysis are elasticity of demand, return on investment and order cost/set up cost. In any business, boom and recession are a common phenomenon depending on various external and internal factors. That means, the players (supplier, manufacturer or retailer) can be either in recession, normal or boom state of market. So, the return on investment can vary in the case of any of these players in an SC system based on the existing market conditions. The following table shows such an analysis how difference in return on investment or the market conditions affects the profit of individual players and overall SC profit.

Table 3.4: Analysis of supply chain profit (case 3 - maximum profit case) for the different market conditions/ values of Return on investment (ROI) of various players ($D_1 = 1000, \lambda_m = 3, \lambda_s = 1, A_r = 30, A_m = 200, A_r = 400$)

Case	Return on investment	λ_m	λ_s	Retailer profit (Rs)	Manufacturer profit (Rs)	Supplier profit (Rs)	Supply chain profit (Rs.)
I	$k_r = 10, k_m = 15, k_s = 20$	3	1	11562235	8811524	8858144	29231904
II	$k_r = 10, k_m = 20, k_s = 15$	3	1	11562235	9043522	8798461	29404219
III	$k_r = 20, k_m = 15, k_s = 10$	3	1	11632264	9020682	8643984	29296930
IV	$k_r = 20, k_m = 10, k_s = 15$	3	1	11708837	8820650	8704013	29233500
V	$k_r = 15, k_m = 10, k_s = 20$	3	1	11601901	8745856	8789760	29137517
VI	$k_r = 15, k_m = 20, k_s = 10$	3	1	11586459	9172128	8669856	29428443
VII	$k_r = 10, k_m = 10, k_s = 10$	3	1	11562236	8922942	8618435	29103613
VIII	$k_r = 15, k_m = 15, k_s = 15$	3	1	11587056	8912452	8750931	29250439
IX	$k_r = 20, k_m = 20, k_s = 20$	3	1	11610695	8914532	8927451	29452678

10% ROI – Recession state, 15% ROI – Normal state, 20% ROI – Boom state

Table 3.4 shows the performance of players under different market conditions/values of return on investment. The above analysis reveals that the state of the manufacturing sector (cases II & VI – boom and cases IV & V– recession) affects more on the total SC profit. This is because the manufacturer is getting the chance to invest the amount to be paid to the supplier and at the same time to receive the interest from the retailer for delaying the payment. But, the retailer has no opportunity to get the interest due to delay in payment from its downstream player even though he has the opportunity to invest the amount to be paid to the manufacturer. Similarly, supplier has the opportunity to receive the interest from the manufacturer but no opportunity to delay the payment to its upstream player and to make the investment. The rate of increase in the SC profit as the whole market condition improves (cases VII, VIII & IX) is almost constant.

The order cost/set up cost is normally highest for manufacturer or supplier and lowest for other players in an SC system. The Table 3.5 shows the analysis of how the variation in order cost/set up cost of various players affects the SC profit. The other parameters such as Elasticity of demand, ROI, Lot size multiplier remains same. It shows that as retailer's order cost increases, the overall SC profit also increases. This study also reveals that mutual change in the order cost between supplier and manufacturer does not affect the overall SC performance provided the retailer's order cost is the same. This phenomenon can be seen in the cases of I &II, III & IV and V & VI. The order/set up costs given for players in each case of VII, VIII & IX are equal but are in an increasing order from VII to IX case. The SC profit is also found to be increasing in the same order compared to the case 1. All these findings show that the order cost of the retailer plays a major role in the performance of the SC. This is due to the fact that when the retailer order cost is high, the retailer's order quantity increases and as a result the retailer's cycle time increases Consequently, the optimal delay in payment of all players changes in such a way that the net savings from investment increases in the case of retailer and supplier. When the order cost of manufacturer or supplier increases (Case V & IX), it affects the SC slightly adverse. The reason is that the order quantity of manufacturer or supplier does not affect the order quantity and their per unit order cost increases. Similar to the above results, the optimal values of delay in payment and price discount changes only when retailer order cost changes. The effect is that the optimal values of delay in payment increases as the order cost of retailer increases and the optimal value of discount given by the retailer increases as the order cost of the retailer increases. But it does not affect the discount given by the manufacturer and the optimal value of discount given by the supplier remains same as zero. The maximum increase in profit with respect to the base case is 2.52% when the retailer order cost is maximum (case VI) and the minimum increase in profit with respect to the base case when the retailer order cost is 0.06% (case VII).The above results and these kind of related insights are also useful for taking appropriate decisions to suit the situations.

Table 3.5: Performance of the players and supply chain profit for different order/set up cost

Case	order/ set up cost A_r A_m A_s	Delay in payment t_{sm} t_{mr} τ_{ms} τ_{rm}	Discount given by each player d_r d_m d_s	Retailer profit (Rs)	Manufacturer profit (Rs)	Supplier profit (Rs)	Supply chain profit (Rs.)	Increase in SC profit (With base as case I)
I	30 200 400	0.000 0.009 0.050 0.009	20.61 10.00 0.00	11587056	8912452	8750931	29250439	0
II	30 400 200	0.000 0.009 0.050 0.009	20.61 10.00 0.00	11587056	8905342	8758041	29250439	
III	200 400 30	0.000 0.024 0.129 0.024	21.11 10.00 0.00	11639946	8882569	9171962	29694477	1.52
IV	200 30 400	0.000 0.024 0.129 0.024	21.11 10.00 0.00	11639946	8887671	9166860	29694477	
V	400 200 30	0.000 0.034 0.184 0.034	21.45 10.00 0.00	11676371	8864368	9454440	29995179	2.54
VI	400 30 200	0.000 0.034 0.184 0.034	21.45 10.00 0.00	11676371	8866027	9452781	29995179	
VII	30 30 30	0.000 0.009 0.050 0.009	20.61 10.00 0.00	11499830	8962616	8806642	29269088	0.06
VIII	200 200 200	0.000 0.024 0.129 0.024	21.11 10.00 0.00	11605083	8902844	9186979	29694906	1.52
IX	400 400 400	0.000 0.034 0.184 0.034	21.45 10.00 0.00	11677210	8861996	9450402	29989608	2.52

As part of the sensitivity analysis, the SC profit while using price discounts along with delay in payments for different price elasticity of demand is also found out and compared with the SC profit under price discounts alone.

Table 3.6: Analysis of supply chain profit under no coordination with price discounts alone and price discounts in conjunction with delay in payments for various cases of elasticity

Sl No	Elasticity of demand	Supply chain profit under price discounts alone as mechanism Jaber.M.Y. et.al (2006) (a)	Supply chain profit under Price discounts along with delay in payments as mechanisms (b)	Percentage of Increase in profit (%) ((b-a)/a)x100
1	1000	28950375	29250439	1.036
2	5000	60743508	61293115	0.905
3	10000	105566572	106317166	0.711
4	15000	150698412	151659658	0.638
5	20000	195992817	197120813	0.576
6	25000	241328917	242570598	0.515
7	30000	286686783	288012060	0.462
8	35000	332057668	333536940	0.445
9	40000	377437082	379013058	0.418
10	45000	422822466	424484781	0.393
11	50000	468212240	469953006	0.372

The Table 3.6 shows that as elasticity increases, the profit increases but the rate profit increase, decreases. This indicates that if the price elasticity of demand is very high, there will not be much benefit by implementing these coordination mechanisms simultaneously to enhance the profit.

3.5 Conclusion

The performance of a three – level supply chain with price discount and delay in payment jointly using mathematical modelling is analysed in this study. From this, it can be concluded that the implementation of the two coordination mechanisms: ‘price discount’ along with ‘delay in payment’ improves SC profit significantly compared to price discount alone (about 1.5% in the case studied). It is also found that the SC profit reaches the maximum in case 3 where the delay in payment period taken from the seller exceeds the buyer's inventory cycle time. So, the 'delay in payment' can be provided more than the buyer's inventory cycle time considering the financial status and past performance of the buyer. Sensitivity analysis reveals the effect of variation of order cost of different players on SC performance provided other's order cost remains same. The overall supply chain profit is seen to increase with the increase in the order cost of the retailer. This indicates that the retailer has a major role in this supply chain system. Sensitivity analysis of return on investment (ROI) shows that the SC profit is most sensitive to the manufacturer's ROI. Rate of increase in profit in the case of a combination of coordination mechanisms studied compared to the case of 'price discount' alone was found to be decreasing with increase in price elasticity of demand. SC managers must understand that using both price discounts and delay in payment produces nearly the same increase in SC profit, over use of only price discount, as that between no coordination and use of price discounts. The SC profit is more sensitive to retailer order cost and manufacturer ROI. The overall analysis indicated that combination of mechanism can be implemented to enhance the profit further after conducting a detailed analysis and considering the related practical aspects.

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Chapter 4

PERFORMANCE OF A NETWORK SUPPLY CHAIN WITH PRICE DISCOUNT AND DELAY IN PAYMENT JOINTLY USING SIMULATION

Contents

4.1 Introduction

Supply Chain Management (SCM) has emerged as an exciting and rewarding topic for researchers and practitioners. In the present business environment, an in-depth understanding of Supply Chain (SC) is a must to succeed. Since, SC spans many organizations; coordination among them is a prerequisite for the success of any SC. SCM deals with the flow of product, fund, information and service. The SC coordination helps to manage these flows to achieve the overall goals of the SC. To ensure SC coordination and to improve its performance thereby, suitable coordination mechanisms have to be implemented individually or in combination based on the nature of the SC. Most businesses have either backorder or lost sales or both. Fulfillment of customer requirement is always the major objective for long term success. The way to achieve this is by implementing proper coordination mechanisms for motivating the SC members to act for overall SC performance and by optimizing inventory and backorder/lost sales.

Simulation is a very useful and well accepted tool for predicting SC performance as discussed under the section 2.3 in the Chapter 2. This part of the study of performance of a networked supply chain with 'price discount and delay in payment' jointly and separately was done using simulation. It was done under both lost sale and backorder cases. Simulation modelling helped us to study the SC coordination with a realistic structure and operating parameters under dynamic business environment and to make the study useful to the academicians as well as practitioners. This study was done based on the already developed computations for profit functions of each player and the final mathematical model of profit maximization discussed in chapter3. In this study, some of the assumptions used in mathematical model were relaxed and added more players at each level of SC to match with reality. SC profit is taken as the performance measure in this study also. A sensitivity analysis is also conducted as a part of this study. Two different products were considered for the study and the data for the same was collected from the industry. The following section deals with SC model, research methods, results & analysis and conclusion.

4.2 Supply Chain Conceptual Model

The structure and operating conditions of SC, assumptions made and notations used in this study are detailed in this section. The diagrammatic representation of the conceptual model is also provided. The detailed description about the business cases and coordination mechanisms is also incorporated to provide a clear concept about the study.

4.2.1 Structure and Operating Conditions

In this study**,** the SC simulated consists of four retailers, two wholesalers and one manufacturer with an infinite part supplier. To coordinate this SC, price discount and delay in payment are used separately and jointly as coordination mechanisms under both lost sale and backorder cases. The conceptual model of this network SC is shown in Figure 4.1. End customer demand and lead time between players are assumed to be probabilistic in nature.

In the case of price discounts, the manufacturer provides a discount to the end customers through his downstream players. So, the customer demand is more than the case of non coordination as the demand is assumed to be price elastic. In this model, a realistic value is taken for the price elasticity for each of the business cases. It is assumed that the manufacturer is not getting any discount from its supplier.

In the case of delay in payments, each player in the SC (upstream player) is ready to provide a permissible delay in payment to his buyer (downstream player) for which no interest has to be paid. In addition to this, there is a provision for the buyer (downstream player) to avail more delay in payment than that permitted, for which interest has to be paid by the buyer (downstream player) to its seller (upstream player), for the period exceeding the permissible delay in payment period. So, if the downstream player avails a delay in payment more than the permitted period by the upstream player, the upstream player will get an additional income in the form of interest from the downstream player. This will usually be done if the downstream player can earn more than the interest to be paid, by delaying payments. Further, the holding cost of each player will be significantly reduced due to delay in payment and consequently the order quantity also increases. In this study, the sellers (manufacturer and wholesalers) lose the opportunity to invest the profit for the period of permissible delay in payment as no interest is charged for that period. But, the retailer does not incur this opportunity cost due to the reason that it is not providing any delay in payment to its customers as only cash sale is assumed to take place. Another important thing is that even though the shipment sent by the upstream player reaches the downstream player (manufacturer to wholesaler and wholesaler to retailer), the upstream player carries its financial burden till the downstream player pays for it. It means that the upstream players incur an additional holding cost for each shipment delivered to the downstream player for a period by which the payment is delayed by the downstream player. This additional holding cost is different from the normal holding cost. It is to be noted that retailers do not incur any additional holding cost as they do not provide any delay in payment to their customers.

In this model, it is assumed that the players are coordinating with each other on order quantity in such a way that each retailer places its EOQ on its wholesaler and each one of the wholesalers in turn places order for the sum of the EOQ of its retailers on manufacturer. The manufacturer gets the raw materials and components from the infinite part suppliers (considered as universe) as per the order for manufacturing. The customer demand and the lead time between two successive players are assumed to be dynamic in nature. In this study, replenishment orders are placed by all players considering the demand during the lead time. In the case of retailers, the replenishment orders (reorder point) are placed considering the expected average demand from their customers during the lead time. In the case of upstream players (wholesalers and manufacturer), the demand during the lead time is equal to the order quantity of his one downstream player. It means that during the lead time, the upstream players are expecting only one order from any one of his downstream players. This is the reason for all the upstream players placing the replenishment order when the inventory reaches the order quantity of his one downstream player to avoid any stock out situation during the lead time. So, the reorder point is the point at which inventory reaches the order quantity of his one downstream player. The overall objective of this ordering policy is to avoid stock out situation and to minimize the inventory cost. In this study, expected variations in demand are only considered and hence safety stock is not in our scope of study.

As mentioned earlier, two business situations are considered in this study. In the case of lost sale situation, the sale is lost if the retailer is out of stock for the SKU demanded; therefore, lost sale may occur. In the case of back order situation, the customers will be ready to wait till the next shipment arrives. These two situations occur only at the retailer-customer interface. In the case of non coordination model, it is assumed that each player places order for its own economic order quantity on its upstream player and no coordination mechanisms are implemented. In this case, unnecessary inventory may pile up and cause more inventory carrying cost and low SC performance. In the non coordination case, all the parameters and operating conditions (no mechanisms) used are the same as those of coordination case. The non coordination model is also analysed for both the business cases.

4.2.2 Assumptions

The following are the assumptions based on which this study of simulation modelling and analysis of a network SC is conducted.

i. Products delivered from the manufacturer are of perfect quality and therefore there is no rejection at any stage.

ii. Delay in payment is permitted and availed by each player from its upstream player without interest and with interest up to a maximum of the buyers inventory cycle time. Manufacturer does not avail and retailers do not permit delay in payment. Similarly, price discounts are given by manufacturer to the customers through its downstream players and manufacturer does not avail discounts from infinite part supplier as it is only a part of SC but not considered for any computation for co-ordination benefits.

iii. Delay in payment with interest (Maximum delay in payment) provided by an upstream player to downstream player is its inventory cycle time.

iv. Price elastic end customer demand, cost parameters do not vary over time and each player is financially capable of settling his/her balance with the preceding player at any point in time in a single payment. Linear storage cost per unit time is taken.

v. The simulation is run for 365 days.

vi. SC either follows lost sales situation or backorder case but not both.

vii. Infinite part supplier is considered as an infinite source and is not considered for the performance measure calculations.

viii. The order quantity of retailer is its EOQ and the order quantities of wholesalers are based on the EOQ of his retailers. Accordingly, each wholesaler orders a sum of the EOQs of his retailers. But the manufacturer schedules the production batch size for a quantity equal to the order quantity of his one wholesaler to minimize the inventory cost.

ix. The maximum number of total annual backorders for each retailer is limited to ten percentage of the total annual expected average demand of each retailer.

x. The retailer keeps enough minimum inventory to ensure that lost sale is occurring only due to the unavailability of product with customer desired features (SKU demanded not in stock)and not due to retailer's zero stock.

xi. No shortage/lost sale is permitted at wholesaler and manufacturer and it will occur only between retailer and customer

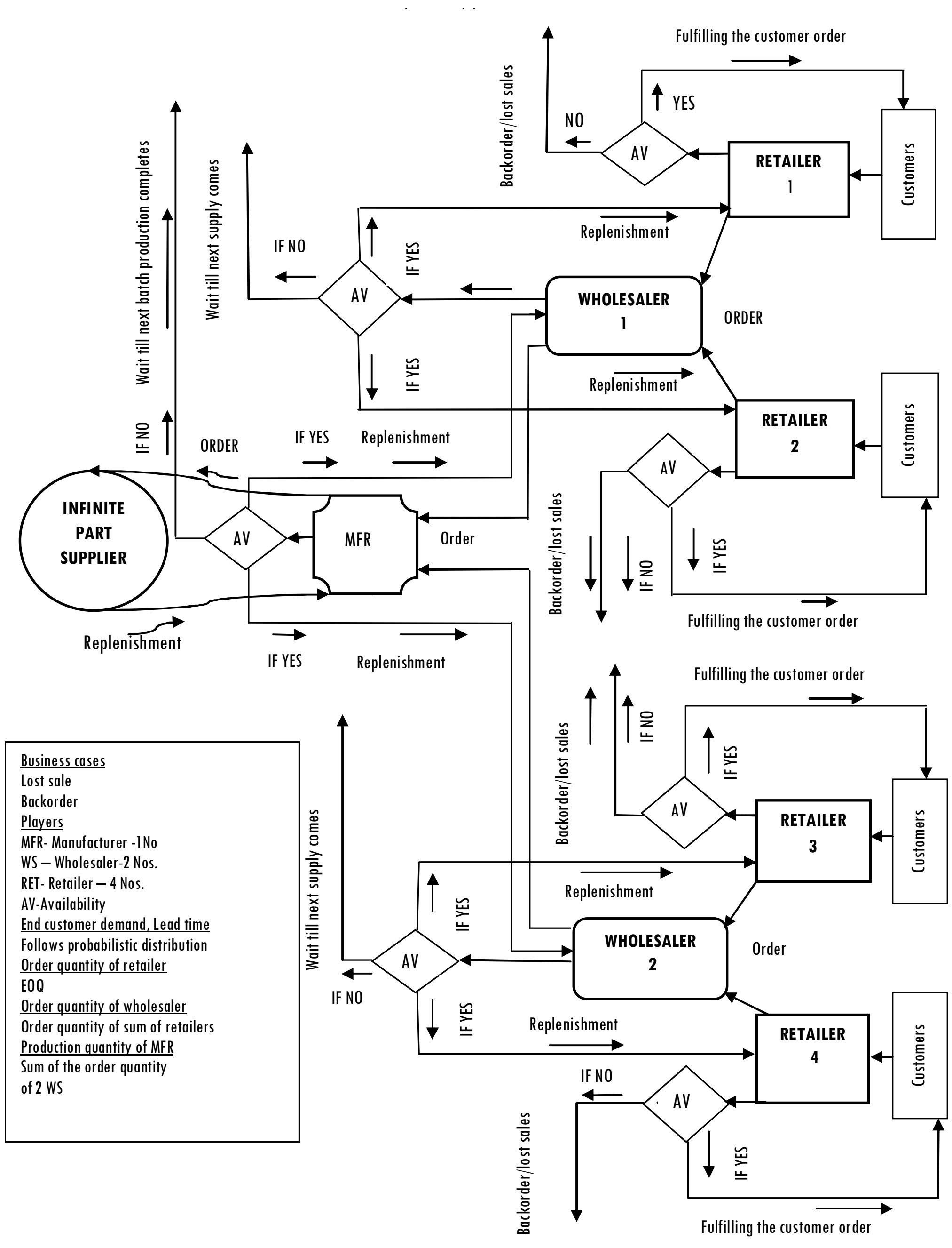

Figure 4.1: A conceptual model of a network Supply Chain consisting of four retailers, two wholesalers and one manufacturer with an infinite part supplier

4.2.3 Notations

i = a subscript identifying a specific player in a SC; $i = s, m, w, r$

(s = supplier, m = manufacturer, w = wholesaler, r = retailer)

A_i = Order cost for player i,

k_i =Return on investment/interest to be paid for player i .

Actual end customer demand $D = D_0 + D_1 \times d_r$, Where d_r = discount given by the retailer, D_0 = Initial demand, D_1 = Elasticity of demand

P_i = Selling price for each player i

S_i = Sales for each player i

C_i = Purchase cost for each player i

hc_i = Holding cost for each player i

sc_i = Storage cost for each player i

$d_i = d_r = d_w = d_m$ = Discount offered by each player

$c_i = (P_i - d_i)$ =Discounted purchase cost for each player i

t_{ij} = Interest free permissible delay in payments period permitted by player ' i ' to player ' j = t_{mw} & t_{wr}

τ_{ji} = Maximum possible delay in payments period availed by player ' j ' from player ' i ' = τ_{rw} & τ_{wm}, If $\tau_{ji} > t_{ij}$, the player ' i charges interest on player j for the period of $\tau - t$

Where $j = w \; r \quad i \neq j$

Q_i = Quantity ordered by each player to its upstream player

q_i = Quantity released by each player to its downstream player

n_{bi} = Number of backorders for each player

n_{li} = Number of lost sales for each player

c_{li} = Lost sales cost for each player

c_{bi} = Backorder cost for each player

t_{di} = Time at which a player dispatches the order quantity to its customer

t_{ri} = Time at which a player receives its order quantity from its upstream player

k_i = Rate of return for each player

T_i = Inventory cycle time for player, $T_i = \dfrac{Q_i}{D}$

4.3 Methodology

In this study, this simulation modelling of a network SC coordination using price discounts and delay in payments separately and in combination under backorder and lost sale cases is done to analyse its performance under various aspects compared to the non coordination case. Initially mathematical modelling is done to develop various expressions for the different parameters of the SC system. Simulation modelling and analysis are done to incorporate the dynamic nature of the various parameters of the SC in the analysis. The SC profit is considered as the performance measure in this study. The SC performance is computed for coordination and non coordination cases with different coordination mechanisms to analyse the effect of implementing these mechanisms for coordination in the SC. A sensitivity analysis is also conducted to analyse the effect of various parameters on SC performance. The following sections deal with the simulation model and profit functions of each stages and the total SC.

4.3.1 Supply Chain Simulation Model

The simulation modelling of the network SC shown in Figure1 is done using “Arena simulation software”. The simulation model of the network SC consists of 3 sections i) network section ii) control section and iii) computation section. The network section shows the flow of entities or products during simulation, whereas control section deals with control and monitoring of movements in network section and finally computation section computes various parameters required for getting net SC profit. In this SC, retailers 1 &2 are linked to wholesaler 1 and retailers 3&4 are linked to by wholesaler 2.The two wholesalers place orders with the manufacturer. The manufacturer in turn gets the required items from infinite part supplier to produce the finished goods for supply to the wholesalers.

Simulation starts with creating raw materials and components at infinite part supplier and supplied to the manufacturer where finished goods are produced equal to the sum of the EOQs of four retailers. Then, the finished goods from the manufacturer are dispatched immediately to the two wholesalers equally and these in turn are dispatched to the retailers concerned equally again. Customer requirement will be started to fulfill continuously as and when the finished goods reach the retailer’s end. This is done only at initial stage to ensure equal inventory at all players of each level. Hereafter, each player places the replenishment orders as per their individual requirement. The retailer places the next order (EOQ) with the wholesaler concerned when his inventory reaches equal to the expected demand from his customers during the lead time. In the case of lost sale, the replenishment orders are placed by the retailer when the inventory reaches maximum demand that is expected to occur during the lead time to ensure no 'lost sale' due to complete 'stock out' situation. In the case of back order, the reorder point at each retailer is fixed in such a way that the maximum number of total annual back orders should less than 10% of the expected average annual demand considering the goodwill of the firm. The reorder point at each wholesaler level is the EOQ of one retailer to avoid stock out situations. The production rate at manufacturer is in such a way that an inventory equal to order quantity of one wholesaler will be always available at manufacturer. Accordingly, manufacturer gets the raw materials and components from infinite part supplier (IPS) and completes the production for a quantity equal to the requirement of one wholesaler in one batch before the existing stock dispatched to the wholesaler. This is always done to ensure the requirement of one wholesaler at the manufacturer. The release of a shipment from a wholesaler or manufacturer to his downstream player occurs when the system satisfies the following two conditions i) the stock at downstream player should reach reorder point (equal to order quantity of his downstream player in the case of wholesalers and manufacturer) ii) the earlier shipment must have reached the corresponding downstream player. To ensure the second condition, a parameter called 'No release time' equal to the maximum lead time between those two players concerned is set in the system. So, a player will always check before it releases the shipment whether it is under 'no release time or not' in addition to the reorder point level condition of the other player. In the case of lost sale situation, the end customer demand is assumed to be normally distributed. Health drink is considered as the product for lost sale situation. In this case, the lost sale will occur only due to non availability of customer desired flavour and retailer will never undergo completely out of stock situation.

To make it possible, the retailer keeps enough minimum inventories (maximum demand as per the demand pattern that can occur during the lead time) to avoid out of stock as the inventory cost is much lesser than lost sale cost. The lost sale cost is one which is incurred by the retailer when lost sale occurs and it is taken as his profit that would have been obtained if the sale had happened. The occurrence of the above mentioned lost sale due to non availability of health drink with desired flavour is assumed to be probabilistic and follows normal distribution in this model. The lead time between players for placing and receiving an order is assumed to follow triangular distribution.

In the case of back order situation, the end customer demand is assumed to follow triangular distribution. In this part of the study, ‘two wheeler’ (bike) is considered as the product for backorder situation and it is assumed that the customer is ready to wait till the next order arrives if the retailer is under ‘out of stock’ or product with customer desired features is not available. The backorders occurred during a particular retailer’s inventory cycle time will be fulfilled from the next shipment and the remaining quantity of that shipment after fulfilling the backorders only will be available at retailer for the business till next shipment arrives. In this case, retailer will incur a backorder cost for each product of the back order and it is assumed to be much less than the profit of the retailer. In this model, it is pre-fixed that the total back order of each retailer during a year should not exceed ten percentage of the total average expected demand of one retailer. The back orders are permitted only at retailer level. The lead time between players for placing and receiving an order is assumed to follow triangular distribution.

The control section of this simulation model regulates the various processes occurring in the network model. The revenue and various costs are calculated in the computation section of the simulation model where all the expressions corresponding to each parameter in the SC profit functions are provided.

In this study, two coordination mechanisms; ‘price discount’, ‘delay in payment’ are used separately and simultaneously to coordinate the SC. In the case of price discounts, an appropriate value for price elasticity is assumed for an optimum value of price discount given by the manufacturer to the customers through his downstream players to enhance the demand as it is price elastic. So, the end customer demand at each retailer will increase based on the value of price elasticity and the discount provided and subsequently the sales revenue also increases. In the case of delay in payments, each downstream player will be provided a permissible delay in payment by its upstream player and for which no interest for the amount has to be paid. But, interest has to be paid by the downstream player to his upstream player for the period that exceeds the permissible delay in payment. In this part of the study, the maximum delay in payment that can be availed by downstream player is his/her inventory cycle time. At the same time, each downstream player can invest this amount to be paid till his/her inventory cycle time and can earn some extra income to his/her revenue. Further, the holding cost of each player will be significantly reduced due to delay in payment and thereby EOQ of each player also increases. Finally, overall performance of the network SC is expected to improve.

The validation of the above mentioned simulation model was conducted by an iterative process of comparing the model to actual system behavior and using the discrepancies between the two, and the insights gained, to improve the model. This process is repeated until model accuracy is judged to be acceptable. The simulation was run for 21 consecutive 365 day periods and outputs were collected avoiding the first year run (to allow for the initialization bias and for the system to acquire steady state) and only the later 20 year simulation outputs were taken for computation. This provided 20 replication data for analyzing the variability using standard deviation of SC profit.

The values of each input parameters are provided in Table 1 and 2 for backorder and lost sales cases respectively and they have been collected from market study done in Kerala. In this study, the simulation run is of 365 days and during the process, cost and revenue occurring on daily basis are calculated and summed to get the net amount of SC profit at the end of the simulation run. Finally, the sum of each cost and revenue during the simulation process for entire period is obtained. The net SC profit obtained at the end of simulation process under various operating conditions is used as the performance measure of the SC.

4.3.2 Performance Measure and its Calculations

The performance measure of the SC in this study is taken as the 'SC profit' and is calculated as the sum of the individual profit of four retailers, two wholesalers and the manufacturer. Simple interest is used for calculating the return on investment and interest on amount of purchase cost to be paid. The profit function of each player is calculated as follows.

4.3.2.1 Retailer Profit

Profit of the retailer = Sales revenue – Net cost 4(1)

Sales revenue $= S_r \times (P_r - d_r)$ 4(2)

Net cost = order cost + procurement cost + storage cost + interest paid to wholesaler+ backorder cost/lost sales cost – savings from investment 4(3)

Quantity ordered by the retailer = $Q_r^* = EOQ = \sqrt{\frac{2CR}{(h_r + s_r)}}$ 4(4)

Discount offered by the retailer to the customer = d_r

Order cost = A_r

Procurement cost $= Q_r \times (P_w - d_w)$ 4(5)

Storage cost $= (sc_r) \times q_r \times (t_{dr} - t_{rr})$ 4(6)

Holding cost $= (hc_r) \times q_r \times (t_{dr} - t_{rr}) = 0$ 4(7)

('Zero' in the case of delay in payments taken by the retailer is equal to (assumed in this study) or greater than its inventory cycle time)

Additional holding cost of retailer =0

(Retailer do not provide any delay in payment to its customers)

Inventory cycle time of wholesaler $= T_r = \frac{Q_r}{D}$ 4(8)

Interest paid to wholesaler $= c_r \times Q_r \times k_m \times (\tau_{rw} - t_{wr})$ 4(9)

Savings from the investments $= c_r \times Q_r \times k_r \times (\tau_{rw})$ 4(10)

Backorder cost $= c_{br} \times n_b$ 4(11)

Lost sales cost $= c_{lr} \times n_l$ 4(12)

4.3.2.2 Wholesaler's profit

Profit of wholesaler = Sales revenue – Net cost 4(13)

Sales revenue $= S_w \times (P_w - d_w)$ 4(14)

Net cost per unit cycle = Order cost + Procurement cost + Storage cost + Holding cost + Additional holding cost + Interest paid to supplier + Cost due to loss of opportunity to invest the profit – (Savings from investment+ Interest paid by retailers) 4(15)

Quantity ordered by each wholesaler = $2*Q_r^*$ 4(16)

Holding cost $=(hc_w)\times q_w\times(t_{dw}-t_{rw})=0$ 4(17)

(‘Zero’ in the case of delay in payments taken by the wholesaler is equal to (assumed in this study) or greater than its inventory cycle time

Additional holding cost = $hc_w Q_r \tau_{rw}$ 4(18)

Storage cost $=(sc_w)\times q_w\times(t_{dw}-t_{rw})$ 4(19)

Inventory cycle time of wholesaler = $T_w = \dfrac{Q_w}{2\times D}$ 4(20)

Order cost = A_w

Procurement cost $=Q_w\times(P_m-d_m)$ 4(21)

Quantity y released by each wholesaler at each time against a retailer order $=q_w$

Interest paid to manufacturer $=c_w\times Q_w\times k_m\times(\tau_{wm}-t_{mw})$ 4(22)

Interest received from retailer $=c_r\times Q_r\times k_w\times(\tau_{rw}-t_{wr})$ 4(23)

Savings from the investments $=c_w\times Q_w\times k_w\times(\tau_{wm})$ 4(24)

Opportunity cost due to delay in payments

$$=(c_r-c_w)\times Q_r\times k_w\times t_{wr} \qquad 4(25)$$

Backorder cost $=c_{bw}\times n_b$ 4(26)

Lost sales cost $=c_{lw}\times n_l$ 4(27)

4.3.2.3 Manufacturer Profit Function

Profit of manufacturer = Sales revenue – Net cost 4(28)

Sales revenue $= Q_w \times (P_m - d_m)$ 4(29)

Net cost = Order cost + Procurement cost + Storage cost + Holding cost + Additional holding cost+ Cost due to loss of opportunity to invest the profit - Interest paid by wholesalers 4(30)

Batch production quantity of manufacturer, $Q_m = 4 \times Q_r = 2 \times Q_w$ 4(31)

Procurement cost $= c_m \times Q_m$ 4(32)

Holding cost $= (hc_m) \times q_m \times (t_{dm} - t_{rm})$ 4(33)

Storage cost $= (sc_m) \times q_m \times (t_{dm} - t_{rm})$ 4(34)

Additional holding cost = $hc_m Q_w \tau_{wm}$ 4(35)

Inventory time of cycle for the supplier $T_m = \dfrac{Q_m}{4 \times D}$ 4(36)

Order cost = A_m

Interest received from wholesaler $= c_w \times Q_w \times k_m \times (\tau_{wm} - t_{mw})$ 4(37)

Opportunity cost due to delay in payments

$$= (c_w - c_m) \times Q_w \times k_m \times t_{mw} \quad 4(38)$$

Backorder cost $= c_{bm} \times n_b$ 4(39)

Lost sales cost $= c_{lm} \times n_l$ 4(40)

4.3.3 Input Data

Health drink and two-wheeler industries are common and familiar to general public. So, this study is expected be more interesting to both business community and academicians as well. Both the industries considered for this study include almost all stages in a typical supply chain so that modelling of the same became realistic one. In the case of two-wheeler, each manufacturer/ dealer follows different procedures to deliver the product to the customer. From the interaction with industry, it is understood that they follow some of the principles of supply chain management even though not in complete aspect. So, we have followed a typical case of supply chain which includes manufacturer, wholesaler/distributor and dealer/retailer for this research. Regarding health drink, due to the nature of this product and its requirement, customers will not wait for it under out of stock situation. So, sale will be lost if a customer comes when the item is not in stock. This is called lost sale. But, people may wait for two wheelers at least a couple of weeks till the next shipment arrives at the retailer end and once it reaches, all the pending orders from customers will be fulfilled at first. This is called backorder. So backorder is also a demand that will be fulfilled later than desired. Each backorder and lost sale incurs an additional cost. The two coordination mechanisms: price discount and delay in payment are being practiced in these two industries in one way or other. So, this research to study the effect of combination of these mechanisms on the SC performance and sensitivity analysis under lost sale and backorder situation using a set of realistic data will be really helpful to the users.

'Health drink' is used as the product under lost ale to suit the situation and it belongs to FMG group. The important factor to use this product is to suit the assumption we have made that lost sale will happen only because of the unavailability of the product with desired flavour. This means that we assume the system will never be completely out of stock under the case of lost sale.

'Two-wheeler' is used as the product under backorder to suit the situation and it belongs to MMG group. The important factor to use this product is to suit the backorder situation. In the case of two wheelers, customers may be willing to wait till the next shipment arrives in the case of complete out of stock situation or unavailability of two-wheeler with desired features.

This study is conducted using the data provided in Table 4.1 and 4.2 for lost sales and backorder respectively and it is collected from the industrial market concerned. The price elasticity for the demand is taken as 1 and 0.001 for lost sales and backorder respectively. Rate of return or interest rate on investment/delay in payment is taken as 15% (normal situation) for both the cases.

Demand per day in the case of health drink (lost sale) was found to be varying in wide range and almost follows normal distribution. With the interaction with industry, it is found that variation in demand per day in the case of two- wheeler (back order) is relatively too low due to nature of the product considered in this study and seems to be matching with triangular distribution. Accordingly, It is assumed that customer demand as normal distribution for lost sales scenario whereas triangular distribution for backorder scenario. Similar to this, it is also assumed that both the occurrence of lost sale and back order follows triangular distribution but the parameter values are taken as different to suit the case of product.

Table 4.1: Input data for lost sale situation (product – health drink)

End customer demand	Player	Purchase cost/unit	Selling price	Discount Provided	Order cost (Rs)	Holding Cost/ unit/year	Lost sale cost/unit	Interest rate (%)	Storage Cost/unit / year
Normal distribution (15, 3)	RET	193	200	3	200	30	7	15	35
	W S	188	193	3	300	29	-	15	23
	MFR	176	188	3	500	28	-	15	20

Note: i) Lost sale due to desired flavour is assumed as probabilistic and follows triangular distribution (0, 0, 1), Price elasticity- 1

ii) Lead time assumed as probabilistic and follows triangular distribution :WS to RET(1,2,3) & MFR to WS (3,4,5)

Table 4.2: Input data for Back order situation (product – bike)

End customer demand	Player	Purchase cost/unit	Selling price	Discount Given	Order cost (Rs)	Holding Cost/unit /year	Backorder cost/unit	Interest rate (%)	Storage Cost/unit / year
Triangular distribution (8,10,12)	RET	45000	50000	3000	10000	5550	500	15	3650
	W S	42000	45000	3000	20000	6750	-	15	1800
	MFR	34000	42000	3000	30000	7500	-	15	1400

Note: i) Colour related B.O is assumed as probabilistic and follows triangular distribution (0, 1, 1), MFR -Manufacturer, WS-Wholesaler, RET-Retailer, Price elasticity - 0.001

ii) Lead time assumed as probabilistic and follows triangular distribution: WS to RET (2, 3, 4) and MFR to WS (5, 6, 7)

4.4 Result and Analysis

The simulation of network SC was conducted using the coordination mechanisms of Price Discount (PD) and Delay in Payment (DIP) individually and in combination (PD & DIP) with coordination on order quantity as explained in preceding sections. Simulation was also conducted with no coordination (no coordination mechanisms are used). In this model, probabilistic demand and lead time are used and hence it is found that the monthly profit values are not the same. When we examined the profit for the first and second set of six months, they are nearly the same indicating that model has achieved steady sate. The results obtained from the simulation runs are given in Table 4.3.

The value of price discount Rs 3/- (lost sale), Rs 3000/- (backorder) and the value of interest free permissible delay in payment ‘zero’ used in this simulation, are the optimal values obtained from sensitivity analysis. But, the value of delay in payment availed by each buyer from its seller for lost sale (16 days) and backorder (13 days) was set as the buyer’s inventory cycle time in this study considering the current practice in industry.

Table 4.3: Supply Chain Performance (SC profit) under Coordination and No coordination

Business Situations	Player	No Coordination: Individual profit of players under No coordination(Rs)	No Coordination: SC Profit (Rs) (std deviation)	Coordination: Coordination Mechanism	Player	Values of coordination mechanism: Price discount (Rs)	Delay in payment (Days): Permitted by each	Delay in payment (Days): Availed by each buyer	Individual SC profit of players under coordination(Rs)	SC Profit (Rs) (std deviation)	% increase in SC profit under 'Coordination' compared to 'No coordination'
Lost sales	M	225037	397778 (2423)	PD	M	3			172878	406118 (1554)	2.10
					W1	3			44963		
					W2	3			45051		
	W1	38788			R1	3			36026		
					R2	3			36311		
					R3	3			35615		
	W2	40282			R4	3			35274		
				DIP	M	-	0	16	232816	423758 (3270)	6.53
					W1	-	0	16	40261		
	R1	24532			W2	-	0	16	40249		
					R1	-	0	16	27982		
					R2	-	0	16	27994		
	R2	24539			R3	-	0	16	27442		
					R4	-	0	16	27014		
				PD & DIP	M	3	0	16	198183	437798 (3044)	10.01
	R3	22706			W1	3	0	16	53250		
					W2	3	0	16	51219		
					R1	3	0	16	33950		
	R4	21894			R2	3	0	16	34253		
					R3	3	0	16	33099		
					R4	3	0	16	33844		
Back order	M	106170018	211201430 (432129)	PD	M	3000		-	94319908	217732132 (951883)	3.09
					W1	3000		-	22312119		
					W2	3000		-	22255138		
	W1	19054754			R1	3000		-	19794685		
					R2	3000		-	19635767		
					R3	3000		-	19727413		
	W2	19952002			R4	3000		-	19687102		
				DIP	M	-	0	13	113968717	219782106 (235810)	4.06
					W1	-	0	13	19064528		
	R1	16477526			W2	-	0	13	19066247		
					R1	-	0	13	16791214		
					R2	-	0	13	17095747		
	R2	16548484			R3	-	0	13	16950675		
					R4	-	0	13	16844978		
				PD & DIP	M	3000		13	91064326	227795878 (1692284)	7.85
	R3	16470534			W1	3000		13	25276285		
					W2	3000		13	24832955		
					R1	3000		13	21569456		
	R4	16528112			R2	3000		13	21688754		
					R3	3000		13	21798595		
					R4	3000		13	21565507		

R1 – Retailer 1 W1 – Wholesaler 1 PD – Price Discounts Maximum Delay in payment availed by the buyer= Buyer's inventory cycle time from the seller
R2 – Retailer 2 W2 – Wholesaler 2 DIP – Delay in Payments
R3 – Retailer 3 M – Manufacturer NC – Non coordination
R4 - Retailer 4

The results given in Table 4.3 obtained from the simulation of network SC for various cases of coordination and no coordination show that the SC profit is enhanced significantly due to coordination under both lost sale and backorder cases. The Standard Deviation (SD) of the profit values obtained from the 20 simulation runs is also given in the table along with mean value of supply chain profit under various cases to have more clarity on the results. The SD is seen to vary from 0.3 to 0.7 % of the mean. The SD being so small implies that, for all practical purposes the mean may be taken as the performance measure. Therefore the change in performance from one case to the next case of use of coordination can be judged from change in mean profit figures of each case. Hence the results given henceforth only mean is shown. Under lost sale, the increase in SC profit is 2.10% in the case of price discounts, 6.53% in the case of delay in payment and 10.01% in the case of a combination of price discount and delay in payment, compared to non coordination. Under backorder, the increase in profit is 3.09% in the case of price discounts, 4.06% in the case of delay in payments and 7.85% in the case of a combination of price discount and delay in payment, compared to non coordination. In the case of delay in payment, increase in SC profit is relatively high compared to the case of price discount under both the cases. This is due to the decrease in total order cost of each player in the case of delay in payment compared to the other. The decrease in total order cost is due to the reduction in per unit order cost by the increase in order quantity with decrease in holding cost because of the effect of delay in payment. The improvement in performance in the case of delay in payment alone compared to price discount alone cannot be generalized as the performance of price discount depends on the price elasticity of demand also. The analysis of the hike in profit of individual players due to coordination shows that manufacturer's profit is reduced due to coordination especially in the case of price discount alone. This is due to the fact that manufacturer is not getting any discount or delay in payment from his upstream player and the manufacturer sacrifices for the overall benefit of the SC. Since the overall SC profit is enhanced owing to coordination, the decrease in profit for the manufacturer under coordination can be made up by proper profit sharing methodology among players to get equal rate of return for each player based on their investment. The individual hike in profit in the case of other players due to coordination is significantly high under lost sale and backorder.

The increase in profit due to coordination varies even for players at the same level. This is due to the dynamic nature of operating parameters including demand and lead time for each player during the period of simulation. As mentioned above, the overall analysis shows that SC profit is significantly enhanced owing to coordination, especially in the case of delay in payment. So, the 'delay in payment' can be implemented as a coordination mechanism considering the investment potential of each player and the possibility of getting the payment after the given delay in payment. Price discount can also be implemented based on the existing or expected price elasticity of demand to improve the performance. In the case of delay in payment, the economic order quantity of the retailer and the order quantity of other players also increases and more quantity of products will be available with each player to meet the demand. So, the end customer demand of the product is very important in the case of delay in payment also to get better performance.

The in depth analysis shows that the increase in SC profit due to coordination is relatively high (except in the case of price discount alone) in the case of lost sale compared to backorder. It indicates that the effect of coordination is relatively high in the case of lost sale as the amount of reduction in cost is relatively high compared to backorder.

4.5 Sensitivity Analysis

A detailed study on the already developed simulation model of SC coordination, using price discount and delay in payment for both lost sale and backorder, is conducted to analyse the effect of various system parameters on the performance of the SC. The sensitivity analysis is conducted for the case of combination of price discount and delay in payment under both lost sale and backorder. In that model, sensitivity of SC profit was checked for changes in price discount values, rate of return, price elasticity, order cost and delay in payment. In all the tables of sensitivity analysis results, bold letters are used to indicate the optimum/recommended values for that parameter. The methodology used, the system parameters considered and the results obtained from the sensitivity analysis are as follows.

Table 4.4 shows the effect of different values of price discount on SC profit under both lost sale and back order cases. This analysis is done by changing the value of price discount as shown in Table 4.4. In the case of lost sale, the maximum SC profit is obtained for a price discount of Rs 3/- (case 3) and in the case of backorder, maximum SC profit is obtained for a discount of Rs 3000/- (case 3) given by the manufacturer to his customers through his downstream players. So, these optimal values of price discount Rs3/- for lost sale and Rs.3000/- for backorder are taken for rest of the sensitivity analysis. The variation in profit for different values of discount is also provided which will help users to take appropriate decision. The SC profit for different values of price discount showed a variation of 2.22% under lost sale and 5.21% under backorder over the five cases examined.

Table 4.4: Supply Chain profit for various price discounts under lost sale and backorder

case	Lost sale			Back order		
	Price discount (Rs)	SC profit (Rs)	Change in SC profit w.r.t Case1 (%)	Price discount (Rs)	SC profit (Rs)	Change in SC Profit w.r.t Case 1 (%)
1	$d_m=d_w=d_r=1$	428353	-	$d_m=d_w=d_r=1000$	224178665	-
2	$d_m=d_w=d_r=2$	431025	0.62	$d_m=d_w=d_r=2000$	227143962	1.32
3	$d_m=d_w=d_r=3$	**437798**	2.20	$d_m=d_w=d_r=3000$	**227795878**	1.61
4	$d_m=d_w=d_r=4$	433334	1.16	$d_m=d_w=d_r=4000$	224069819	-0.04
5	$d_m=d_w=d_r=5$	428270	-0.01	$d_m=d_w=d_r=5000$	216514760	-3.41

Table 4.5: Supply Chain profit for various rate of return under lost sale and backorder

Case	Lost sale			Back order		
	Interest rate (%)	SC profit (Rs)	Change in SC Profit w.r.t Case 1 (%)	Change in SC profit w.r.t Case 1 (%)	SC profit (Rs)	Change in SC Profit w.r.t Case 1 (%)
1	$k_r = 15, k_w = 15, k_m = 15$	437798	-	$k_r = 15, k_w = 15, k_m = 15$	227795878	-
2	$k_r = 10, k_w = 10, k_m = 10$	416891	-4.78	$k_r = 10, k_w = 10, k_m = 10$	225232140	-1.12
3	$k_r = 20, k_w = 20, k_m = 20$	**458706**	**4.78**	$k_r = 20, k_w = 20, k_m = 20$	**230359615**	**+1.12**
4	$k_r = 15, k_w = 15, k_m = 20$	438328	0.12	$k_r = 15, k_w = 15, k_m = 20$	227895918	0.04
5	$k_r = 15, k_w = 15, k_m = 10$	437269	-0.12	$k_r = 15, k_w = 15, k_m = 10$	227695837	-0.04
6	$k_r = 20, k_w = 15, k_m = 15$	447753	2.27	$k_r = 20, k_w = 15, k_m = 15$	229119839	0.58
7	$k_r = 10, k_w = 15, k_m = 15$	427843	-2.27	$k_r = 10, k_w = 15, k_m = 15$	226471916	-0.58
8	$k_r = 15, k_w = 20, k_m = 15$	448222	2.38	$k_r = 15, k_w = 20, k_m = 15$	228935613	0.50
9	$k_r = 15, k_w = 10, k_m = 15$	427375	-2.38	$k_r = 15, k_w = 10, k_m = 15$	226656142	-0.50

Table 4.5 shows the effect of change in the rate of return of different players on SC profit under both lost sale and backorder. Case 1 is the base case and it indicates normal situation. Case 2 indicates recession situation (decreased rate of return) and case 3 indicates boom situation (increased rate of return) for all the players and the rest of the cases are the mixture of the first three situations for each player. From the Table 4.5, it is clear that there is a proportional change in SC profit with change in rate of return of any player. Therefore, the return should be kept at highest possible level by each player. But, it is clear that the individual effect of change in rate of return of wholesaler and retailer is relatively high compared to manufacturer and this trend is also the same under lost sale and under backorder. The variation in SC profit over the nine cases examined is 9.56% under lost sale and 2.24% under backorder.

Table 4.6 shows the effect of different values of price elasticity on the SC profit for an optimum price discount obtained earlier under both lost sale and backorder. The analysis shows that the SC profit is increasing with increase in price elasticity and the rate of increase in profit is almost constant for both the business situations. However, it is noted that the SC profit levels are consistently higher in backorder case. The base case taken here (Case 1) has a situation where discount is given but no increase in demand occurs as price elasticity of demand is zero. The SC profit for different values of price elasticity showed a variation of 91.37% under lost sale and 121.08% under backorder over the five cases examined.

Table 4.6: Supply Chain profit for different cases of price elasticity under lost sale and backorder

Case	Price elasticity of demand (D_0)	Lost sale		Back order		
		SC profit (Rs)	Change in SC profit w.r.t case 1 (%)	Price elasticity (D_0)	SC profit (Rs)	Change in SC Profit w.r.t case 1 (%)
1	0	353604	-	0	173519098	-
2	1	437798	23.81	0.001	227795878	31.28
3	2	522545	47.77	0.002	281857276	62.43
4	3	596524	68.69	0.003	329350527	89.80
5	**4**	**676716**	**91.37**	**0.004**	**383621497**	**121.08**

Table 4.7 shows the SC profit for different values of order cost under lost sale. The case 1 is the base case. The detailed analysis shows that the equal change in the order cost of all players on the upper side (case 2) reduces the SC profit and the lower side (case 3) increases the SC profit almost equal in magnitude in both the cases. The individual increase in the order cost of retailer (case 4) reduces the SC profit relatively less than the case of individual increase in order cost of wholesaler (case 5) or manufacturer (case 6). This is due to the

fact that only in the case of the retailer, change in the order cost results in compensating change in the order quantity through EOQ. Order cost change for the wholesaler and the manufacturer does not result in any compensating order quantity change. Hence it directly affects the SC profit. It is also found that when the order cost is reduced for the retailer (cases 3 & 7), the optimal price discount is also reduced from Rs.3/- to Rs 2/- and remains the same as Rs 3/- for all other cases, as the order cost of the retailer plays a major role in this model. The SC profit for different cases of order cost showed a variation of 5.17% under the lost sale over the nine cases examined.

Table 4.7: Supply Chain profit for various cases of order cost under lost sale

Case	Order cost (Rs)	SC profit (Rs)	Optimal value of discount (Rs)	Change in SC profit w.r.t Case 1 (%)
1	$A_r = 200, A_w = 300, A_m = 500$	437798	3	-
2	$A_r = 250, A_w = 375, A_m = 625$	426367	3	-2.61
3	$A_r = 150, A_w = 225, A_m = 375$	**449039**	**2**	**2.56**
4	$A_r = 250, A_w = 300, A_m = 500$	434930	3	-0.65
5	$A_r = 200, A_w = 375, A_m = 500$	434236	3	-0.81
6	$A_r = 200, A_w = 300, A_m = 625$	431673	3	-1.39
7	$A_r = 150, A_w = 300, A_m = 500$	438114	2	0.07
8	$A_r = 200, A_w = 225, A_m = 500$	441361	3	0.81
9	$A_r = 200, A_w = 300, A_m = 375$	443377	3	1.27

Table 4.8 shows the effect of various cases of order cost on SC profit under backorder. The case1 is the base case. The detailed analysis shows that the increase in the order cost of all players (case2) reduces the SC profit and a decline in the order cost (case 3) of all players increases the SC profit. The individual effect of the retailer (cases 4&7), the wholesaler (cases 5 & 8) and

the manufacturer (cases 6 & 9) on SC profit is same as found in the case of lost sale and the reason also remains same. It is also found that when the order cost is reduced for the retailer (cases 3 and 7), the optimal price discount is also reduced from Rs.3000/- to Rs.2000/- and remains the same as Rs.3000/- for all other cases. The above findings are similar for the lost sale and the backorder case and the extent of effect may be slightly different, depending on the difference in values of the order cost considered. The SC profit for different cases of order cost showed a variation of 0.64% under backorder over the nine cases examined.

Table 4.8: Supply Chain profit for various cases of order cost under back order

Case	Order cost (Rs)	Optimal Value of discount	SC profit (Rs)	Change in SC profit w.r.t Case 1 (%)
1	$A_r = 10000, A_w = 20000, A_m = 30000$	3000	227795878	-
2	$A_r = 12500, A_w = 25000, A_m = 37500$	3000	226976856	-0.35
3	$A_r = 7500, A_w = 15000, A_m = 22500$	**2000***	**228456778**	**0.29**
4	$A_r = 12500, A_w = 20000, A_m = 30000$	3000	227606856	-0.08
5	$A_r = 10000, A_w = 25000, A_m = 30000$	3000	227528377	-0.12
6	$A_r = 10000, A_w = 20000, A_m = 37500$	3000	227360877	-0.19
7	$A_r = 7500, A_w = 20000, A_m = 30000$	2000	227679278	-0.05
8	$A_r = 10000, A_w = 15000, A_m = 30000$	3000	228063377	0.12
9	$A_r = 10000, A_w = 20000, A_m = 22500$	3000	228230877	0.19

Table 4.9 shows the effect of different cases of delay in payment between various players on SC profit. Case 1(base case) shows the optimal values of delay in payment for which maximum SC profit is obtained. Case 2 &3 shows that the change in permissible delay in payment given by the manufacturer to the wholesaler (case3) affects more than the same given by wholesaler to the retailer (case 2) on the SC profit. But, the cases 6 & 7 shows that the effect of change in delay in payment taken by the wholesaler from the manufacturer (case 6) on the SC profit is relatively high, compared to the same

taken by retailer from the wholesaler (case7). It is also found that the increase in permissible delay in payment given by the upstream payers (case 4) and decrease in delay in payment availed by the downstream players (case 5) reduces the SC profit. It is also noted that delay in payment taken by the retailer from the wholesaler does not have much effect on SC profit under both lost sale and back order. It is assumed that the maximum delay in payment taken by the downstream player form the upstream player is its inventory cycle time under both lost sale $(\tau_{rw} = \tau_{wm} = T_r = T_w = 16)$ and backorder $(\tau_{rw} = \tau_{wm} = T_r = T_w = 13)$ cases. The SC profit for different cases of delay in payment showed a variation of 0.084% under backorder and 0.039% under lost sale over the seven cases examined.

Table 4.9: Supply Chain profit for various cases of Delay in payment under lost sale and backorder

Case	Lost sales (LS)			Back order (BO)		
	Delay in payment	SC profit (Rs)	Change in SC profit w r t. case 1 (%)	Delay in payment	SC profit (Rs)	Change in SC Profit w.r.t case 1 (%)
1	$t_{mw}=0, t_{wr}=0,$ $\tau_{rw}=\tau_{wm}=16$	**437798**	**0**	$t_{mw}=0, t_{wr}=0,$ $\tau_{rw}=\tau_{wm}=13$	**227795878**	-
2	$t_{mw}=0, t_{wr}=1,$ $\tau_{rw}=\tau_{wm}=16$	437671	-0.029	$t_{mw}=0, t_{wr}=1,$ $\tau_{rw}=\tau_{wm}=13$	227787048	-0.003
3	$t_{mw}=1, t_{wr}=0,$ $\tau_{rw}=\tau_{wm}=16$	437557	-0.055	$t_{mw}=1, t_{wr}=0,$ $\tau_{rw}=\tau_{wm}=13$	227709467	-0.037
4	$t_{mw}=1, t_{wr}=1,$ $\tau_{rw}=\tau_{wm}=16$	437430	-0.084	$t_{mw}=1, t_{wr}=1,$ $\tau_{rw}=\tau_{wm}=13$	227706637	-0.039
5	$t_{mw}=0, t_{wr}=0,$ $\tau_{rw}=\tau_{wm}=15$	437787	-0.025	$t_{mw}=0, t_{wr}=0,$ $\tau_{rw}=\tau_{wm}=12$	227757502	-0.016
6	$t_{mw}=0, t_{wr}=0,$ $\tau_{rw}=16, \tau_{wm}=15$	437783	-0.034	$t_{mw}=0, t_{wr}=0,$ $\tau_{rw}=13, \tau_{wm}=12$	227757502	-0.016
7	$t_{mw}=0, t_{wr}=0,$ $\tau_{rw}=15, \tau_{wm}=16$	437802	0.009	$t_{mw}=0, t_{wr}=0,$ $\tau_{rw}=12, \tau_{wm}=13$	227795877	-0.000

Note $\tau_{rw}=\tau_{wm}=16=T_r=T_w=$ Inventory cycle time (LS), *Note* $\tau_{rw}=\tau_{wm}=13=T_r=T_w=$ Inventory cycle time (BO)

Table 4.10 shows the consolidated statement of increase in SC profit in each case with respect to each other case of coordination and no coordination. This analysis shows that the percentages of increase in SC profit is relatively high in the case of combination of PD & DIP (LS -10.03% & BO – 7.85%) and DIP (LS -6.53% & BO – 4.06) with respect to non coordination (NC) under lost sale compared to the backorder. Similarly, the increase in profit in the case of DIP and PD&DIP compared to PD is also high in the case of lost sale. The increase in profit in the case of PD & DIP compared to DIP is almost the same under both lost sale and backorder. But, when comparing NC and PD, an increase in SC profit in the case of price discounts is slightly higher under backorder than lost sale. Similarly, when comparing DIP and PD&DIP, an increase in profit in the case of PD&DIP is also slightly higher under back order than lost sale. The overall analysis shows that the increase in profit while using PD and DIP simultaneously is significantly high compared to any other cases under both lost sale and backorder. This comparative statement of increase in profit with each other will help the practitioners to implement the same considering all related practical issues.

Table 4.10: Increase in profit with respect to one case to other case of coordination and no coordination

Case	Lost sale				Back order			
	SC profit	Increase in profit w r t NC (%)	Increase in profit w r t PD (%)	Increase in profit w r t DIP (%)	SC profit	Increase in profit w r t NC (%)	Increase in profit w r t PD (%)	Increase in profit w r t DIP (%)
NC	397778	-	-	-	211201430	-	-	-
PD	406118	2.09	-	-	217732132	3.09	-	-
DIP	423758	6.53	4.34	-	219782106	4.06	0.94	-
PD&DIP	437798	10.06	7.80	3.31	227795878	7.85	4.62	3.64

NC- Non coordination, PD-Price discounts, DIP-Delay in payments

4.6 Conclusion

This study conducted on network SC was to analyze its performance under coordination using different mechanisms and 'no coordination' for lost sale and backorder cases. The operating conditions of the SC in this study are made dynamic in nature to make the system realistic and useful to the business community. Apart from this, the modelling and analysis of the network SC is conducted under both lost sale and backorder cases which represent SC in most business systems. Price discount and delay in payment are the two common mechanisms used separately and jointly to coordinate the SC in this study. This will help the practitioners to know the relative benefits of each case compared to the other and to take appropriate decisions considering all aspects. Sensitivity analysis conducted in this study to analyze the impact of various system parameters on the SC performance will further help in the case of variation in operating conditions. It also reveals the incremental profit for each case with other. In each case of analysis, the extent of benefit that can be obtained from coordination is found out, which is to the extent of 8 % in the case of back order and 10% in the case of lost sale compared to non coordination.

The overall analysis shows that coordination improves the performance of the SC significantly. Among the two coordination mechanisms, the effect of delay in payment on SC performance is found to be slightly better compared to the case of price discount. This is due to the decrease in total order cost of each player due to increase in order quantity by the effect of delay in payment provided by the wholesaler to the retailer. This, in turn, increases the order quantity of the wholesaler and the manufacturer as it depends on the order quantity of the retailer. Apart from all these factors, the price elasticity of demand is also a major factor to decide the effect of price discount on the SC performance. So, we cannot always say that the effect of delay in payment on

SC performance is better than the effect of price discount. However, the joint effect of price discount and delay in payment further improves the profit significantly compared to the individual use of these coordination mechanisms. The manufacturer and the wholesaler improve their performance by ordering the sum of EOQ of their retailers and sum of the ordering quantity of wholesalers respectively. This individual improvement in performance of each player is due to the reduction in inventory cost by keeping the products exactly as per the requirement of the downstream player for minimum possible time to avoid both stock out and excess stock. Finally, this coordination on order quantity also supports the overall performance of SC under each case of coordination mechanisms.

The sensitivity analysis conducted in this study is to understand the effect of change in various operating parameters and to take thereby; appropriate decisions according to better control the sensitive parameters. It helped in quantifying the effect of decision variables on SC profit. This kind of insight is useful to a practicing SC specialist who has to decide which variable to control and how much to control. Analysis on various cases of price discount gave us the optimum value of price discount for the given set of input data collected from the concerned industry for lost sale and back order cases. This being specific cases, the numerical results obtained are not directly applicable to other cases. However, the general trends and more so, the methodology followed for the sensitivity analysis may be used to gain insights regarding the effect of changes in decision variables on SC profit.

Chapter **5**

EFFECT OF INFORMATION SHARING ON THE PERFORMANCE OF A FOUR LEVEL SERIAL SUPPLY CHAIN UNDER BACK ORDER AND LOST SALE SITUATIONS

Contents

5.1 Introduction

Supply Chain Management (SCM) is the handling of product flow, fund flow, information flow and services flow in a business system. An important performance measure for a Supply Chain (SC) is the 'total SC profit' (SC surplus). Coordination between SC partners is required to produce higher SC Profit. Information sharing is one of the best mechanisms to ensure and enhance the SC coordination. Literature shows that the lack of coordination and information sharing causes the bullwhip and finally it affects the performance of SC adversely. Chen et al. (2000) studied the impact of forecasting, lead times and information on bullwhip effect in an SC and quantified the same. They proved that the bullwhip effect can be reduced, but not completely eliminated, by centralizing demand information. Studies reveal that the lack of information sharing affects SC responsiveness, inventory cost, replenishment lead time, transportation cost, etc. adversely and they support the importance of this study.

It is already found that simulation is a very useful tool for predicting SC performance. Simulation with live players is a good methodology as it involves the effect of human behaviour on the study. Unlike earlier studies with ‘price discount and delay in payment’ discussed in the preceding chapters, some other performance measures relevant to Information Sharing(IS) mechanism such as evaluation of bullwhip effect, fill rate or service level, inventory cost and total cost are considered in this study. These performance measures are interrelated and they affected adversely due to the lack of information sharing. So, the study of the effect of different kinds of information sharing on these performance parameters will certainly help us to take appropriate decision. Almost all business in the world will have a characteristic of either lost sale or backorder. Lost sale means that sale will be lost in the case of out of stock situation and backorder means that customers are ready to wait for some time or till the next lot comes if the required item is out of stock. So, the study on the effect of information sharing on SC performance under lost sale and backorder situation is expected to be a significant one for all the users.

During the literature survey in the area of SC coordination using information sharing, the following gaps were noted. In almost all studies, only two-level SC is used as it is a basic structure and it does not provide a complete picture of a real SC. So, the studies with SC having more number of levels are required. Further to this, analysis on the effect of different type of information sharing (IS) cases on the SC performance and comparison with each other are very useful for SC practitioners to take an appropriate decision on the selection of information sharing. But, these kinds of studies are fewer in literature. Studies on SC with different types of IS under both lost sale and backorder situations were not found in the literature. Simulation studies using live players to act out the role of players in the SC too were not found in the literature. Above all, studies with realistic input data and results with the support of statistical tests are also scanty in the literature. Considering all the above mentioned gaps, we have conducted this study incorporating the following factors.

In this part of the study, we have used a four level SC structure with one player at each level to analyse the performance under different types of information sharing cases. Eight different types of information sharing cases are used in this study to analyse the effect of details of information on the SC performance. Back order and lost sales situations are used in this study as most of the businesses have either lost sale or backorder situation. The other operating conditions such as lead time, nature of demand were also made realistic to make this experimental study relevant to the SC practitioners as well as academicians. Further, we have evaluated the performance of the SC for various parameters in addition to total cost which revealed the SC performance under different aspects and made the study more useful. We have done this study by conducting enough number of experiments by our trained students rather than doing in a completely software based simulation to incorporate an element of human psychology in the study. So, this study contributes to the literature by examining the following also:

- The effect of various types of IS on the performance of a four level SC with comparison to each other
- Effect of IS as mentioned above under backorder and lost sale cases and comparison with each other to get a clear picture of the same under different business cases.
- As the simulation is done using live players (students acted the role of each player in the SC), an element of human behaviour could be included in this study. This helped us to get some unusual findings which also make the study something different.

- The data used in this study are obtained from the industry which makes the study further realistic.
- Above all, statistical significance of the results obtained in this study is also examined which provides a scientific support for the same.

5.2 Supply Chain Simulation Model

The Supply Chain Role Play Game (SCRPG) software used in this study is designed and developed for a four level serial SC and it consists of four players - one at each level, a retailer, a distributor, a wholesaler and a manufacturer. The structure of the SC used in this game software is shown in Figure 5.1.

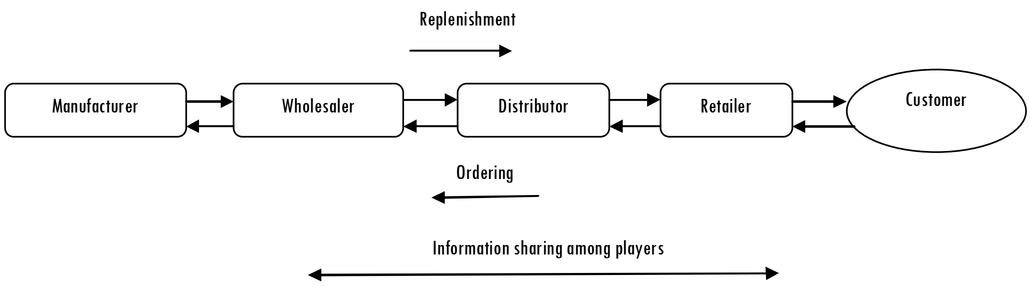

Figure 5.1: Structure of the Supply Chain

The above mentioned 'SCRPG' simulation software was used to conduct the experiments in this study to evaluate the SC performance corresponding to different type of information sharing. This simulation software has been developed at Department of Mechanical Engineering, National Institute of Technology (NIT), Calicut, Kerala, India, in the year 2010. Pamulety and Pillai (2010) reported the development of the 'SCRPG' and have described it in detail. Their work using this 'SCRPG' to study the impact of history of Customer Demand Information (CDI) on bullwhip effect of a four level serial SC is reported by Pamulety and Pillai (2011).

The game can be conducted under eight different kinds of information sharing cases, with backorder and lost sales situations using this software. In each of these situations, customer places the order with the retailer, the retailer with the wholesaler, the wholesaler with the distributor and finally distributor with the manufacturer. Once the retailer receives the order from the end customer, it will be filled with on hand inventory. If the available quantity is not sufficient to fill that order, the unfilled order quantity will be either backordered or it will be considered as lost sales depending upon the settings in which game is being played. If the available quantity is more than the order received from the downstream player, the remaining quantity will be carried over to the next period. These processes are the same for all the players in the SC. Each player places the order with its upstream player at the end of each period and reaches it at the upstream player after a fixed time gap as per the given lead time (taken as zero in this study) which is called order lead time. Shipment quantity reaches from each upstream player to its downstream player after a fixed time gap which is called replenishment lead time. At each player, a period begins with the arrival of shipment from upstream player and receipt of orders from downstream player. The quantity to be ordered is decided by each player considering the available information about order quantity from downstream player, inventory, total lead time, standing backorder, shipment in transit, etc. The sum of the order lead time and the replenishment lead time is taken as total lead time between placing an order and receipt of the same and this can be set in the software. The holding cost, backorder cost, lost sales cost for each level, nature of end customer demand, type of information sharing being used and the number of periods to be played and period to be considered for evaluating the performance can also be set in the game software as per the requirement. It is to be noted that ‘a period’ is equivalent to a week in this study. The operation flow chart of the ordering policy followed in this study is given in Figure 5.2

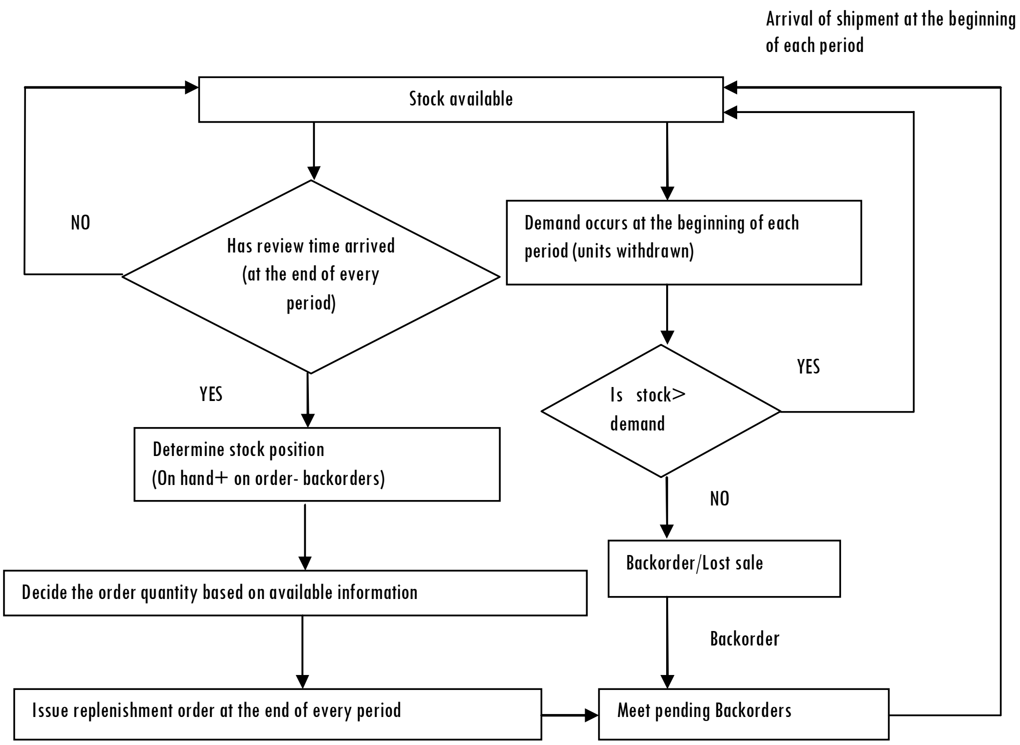

Figure 5.2: Operational flow chart of ordering policy

To conduct each experiment/game, four trained persons and a network of five computers are required with one for each player in an SC and a server computer system. In the server system, all the input data such as registration of players, nature of demand, lead time, the number of periods (weeks by default) to be played for one game, period of evaluation of performance and information to be shared, etc. can be set up as per the requirement of each game. The nature of demand can be assigned as either normal distribution or uniform distribution (demand can be set manually also) while lead time can be provided as the number of periods in the game software.

The sections that follow deal with the assumptions made in this SC role play game software, the types of information sharing and performance measures used.

5.2.1 Assumptions

The SC role play game software used in this study has the following assumptions:

- End customer demand follows a normal distribution.
- Each stage receives shipment from its supplier at the beginning of a period.
- Shipment to downstream stage is done in a period only after replenishment from upstream stage
- Order is placed to upstream stage only at the end of a period
- Review for ordering is done in every period
- Demand from customer for each period is faced by the retailer
- There is no storage capacity constraint at any stage of the SC
- The factory has infinite production capacity and enough raw materials for production.
- The cost parameters are not varying with respect to time.
- Except backorder cost/lost sales cost and holding cost, no other costs are considered in this study.

5.2.2 Types of Information Sharing

The following are the eight different types of information sharing used in this study

- **Traditional (TDL)** -Order placed by a particular stage to its upstream stage is the only information shared between those two stages in the SC

- **Advance demand information (ADI)**- Distribution of the customer demand to be faced by the retailer is shared with all stages
- **Customer demand per period(CDPP) –** End customer demand arises at retailer in each period is shared to all other stages
- **Customer demand history (CDH)** - End customer demand at the retailer for all previous periods is updated and shared with all stages. It is the actual demand raised by the end customer. Theoretically there is no difference between the 3rd and 4th case. But, practically the upstream players may not keep end customer demand shared by the retailer regularly and even though it is maintained, it may not be uniform at all players of the SC. There is a chance of errors occurring and they may affect the performance adversely.
- **Point of sales data per period (PSDPP**)-The sales quantity in a particular period at the retailer stage is shared to all other stages in that period.
- **Point of sales data history (POSDH) –**The sales quantity at retailer stage of all previous periods is updated and shared with all stages. Point of Sales data means the actual quantity of items sold by the retailer to the end customer in each period. This need not be equal to the demand raised, as the available stock may be sufficient to meet the end customer demand. So, the sales quantity will be equal to either the demand or the quantity available in stock.
- **Forecast demand information sharing (FDIS**) **–** The customer demand is forecast by n-period moving average method and will be shared with all stages in each period. If sufficient (n- period) data is not available, the average value and standard deviation for the available

history of customer demand data is calculated and shared to all stages in each period.

- **Demand and SC performance information sharing (D&SCPIS**) - Latest period demand, latest period demand met, and latest period inventory of each stage is shared with all stages in addition to the information of orders placed by each stage.

5.2.3 Performance Measures

The following parameters are used in the SC role play game software to evaluate the SC performance.

- Bullwhip effect (BWE)
- Fill rate
- Lost sales/Back order cost
- Total cost of SC

5.2.3.1 Performance Measure Calculation

The expressions used for calculating the performance measures in 'SC role play game' are given in sections below.

5.2.3.2 Bull Whip Effect

Bullwhip effect is the phenomenon of amplification of order size variation as one move up the SC. It is calculated using the variance of orders at the first stage and last stage of this four stage SC obtained by conducting the experiment.

Variance of orders,

$$\sigma_i^2 = \frac{\sum_{t=1}^{n} (O_t^i - \overline{O_i})^2}{n-1} \qquad 5(1)$$

Where

n	–	Number of time periods
O_t^i	–	Order quantity of stage i in period t
i	–	Stage index in the SC, i = 1, 2, 3, 4
t	–	Time period in weeks, and

$$\overline{O}_i = \sum_{t=1}^{n} O_t^i \Big/ n. \qquad 5(2)$$

Bullwhip effect

$$\text{BWE} = \frac{\text{Variance of orders placed by last stage in a supply chain}}{\text{Variance of customer demand at retailer stage}} \qquad 5(3)$$

5.2.3.3 Fill Rate

The retailer fill rate measures the SC fill rate or customer service level (it is given in %) and it can be calculated as follows.

$$\text{Fill rate} = \frac{\text{demand met}}{\text{demand arisen}} \times 100 \qquad 5(4)$$

5.2.3.4 Total Cost

Total cost of SC is taken as the overall performance measure of the SC and it is equal to the sum of the inventory holding and lost sales/Backorder cost (it is given in Indian Rupees) and it can be calculated as follows.

Total cost=Back order cost/lost sales cost+ Inventory cost 5(5)

5.2.4 Data Used

The data used for this study is collected from the industry market concerned of two different products suitable for back order (Car) and lost sales (Fabric stiffener) situation. We have selected these products to suit the business situations. In this study, simulation software called 'Supply Chain Role Play Game (SCRPG)' is used. In this software, weekly demand is considered by default. So, we could consider car as product under backorder as its weekly demand is sufficient to incorporate backorder and also for related computations. Fabric stiffener is considered for lost sale situation as it also suits the situation of lost sale. We have obtained the data from the industry by interacting with the executives of the concerned industry. We have made small required changes to the input data obtained without affecting its originality to suit the model. All these exercises have been done to make the study realistic as far as possible and expecting the results should be useful to the practitioners and other academicians for their further reference or study. The characteristics of back order and lost sale are already explained in the preceding chapters.

Table: 5.1: Data used for the product under 'lost sales situation' – Fabric stiffener (assumes that demand follows normal distribution)

Retailer	Weekly end customer demand	Opening stock (Nos.)	Lost sales cost/unit (Rs)	Lead time (week)	Holding cost/ unit/ week (Rs)
Retailer	Mean=120 Std. deviation=10	120	7	1	0.25
Distributor		120	3	1	0.2
Wholesaler		240	4	2	0.15
Manufacturer		240	6	2	0.1

Table: 5.2: Data used for the product under 'backorder situation' – Car (assumes that demand follows normal distribution)

Party/player	Weekly end customer demand	Opening stock (Nos.)	Backorder cost/unit (Rs)	Lead time (week)	Holding cost/ unit/ week (Rs)
Retailer	Mean=6 Std. deviation=1	12	9000	1	1030
Distributor		12	6000	1	980
Wholesaler		12	7000	1	920
Manufacturer		24	10000	2	770

5.3 Research Methods

The experiments in this study to evaluate the SC performance corresponding to different types of information sharing under two business situations were conducted using simulation software "Supply Chain Role Play Game" (SCRPG) discussed in the preceding sections. The game can be conducted for any number of periods (weeks by default) using this software. In this study, 'Fabric stiffener' is considered as the product under lost sales situation and 'Car' is considered as the product under backorder situation. The end customer demand is considered as normally distributed under both the situations. The order lead time is taken as zero and a certain number of weeks are assigned for replenishment lead time for different stages for two business situations and the details are provided in Table 5.1 and 5.2.The opening stock at each stage considered in this study is based on the expected demand during the lead time. The game was conducted for 40 weeks and the evaluation of performance is made only for 30 weeks from the sixth week to thirty fifth week (exempting first 5 and last 5 weeks) nullifying the start and end game effect of the experiment.

The entire experiments were conducted with the trained final year UG students having sufficient SCM background. Initially, the students were divided into different groups consisting of four members in each one. Each group consisting of four student volunteers was used for a game. One student each played the role of retailer, distributor, wholesaler and manufacturer in the SC. To conduct the game using these four student volunteers, a network of five computers with one for each player in an SC and the fifth one as a server computer system. In the server system, all the input data such as registration of players, nature of demand, lead time, opening stock, the number of periods (weeks by default) to be played for one game, period of evaluation of performance and information to be shared were set in the software as per the requirement of each game. In the game, the student playing a particular role was required to decide the order quantity in each period and it is done based on the information available to him. The game was conducted for sixteen cases of information sharing and it consists of eight cases in backorder situation and eight cases in lost sale situation. Initially, the game for a particular case was repeated with a set of four member group of trained student volunteers. Observations were collected only after the game reached a steady state. Ten replications were done for every case with different sets of student volunteers; to take care of player related influence on the results. The average of these ten observations in a particular case was taken as the result for that case. This procedure was followed for experiments in all the sixteen cases.

The performance measures captured from each game are fill rate, bullwhip effect, lost sales cost/backorder cost and total cost and all these measures are taken for the analysis. In this study, the ten steady state values of total cost and its average obtained for each case are tabulated and the performances of one compared with the others. This study also prepared a detailed comparative statement of the average of all the steady state SC performance measures and ranked the cases based on the different performance measures. The improvement in overall performance under each type of information sharing compared to the traditional case under lost sales and backorder situations are also analysed in this study. The‘t test’ is used to analyse the statistical significance of the difference found between a pair of overall performance measure (total cost) corresponding to two particular information sharing cases.

5.4 Results and Analysis

This study on a four stage SC system to analyse its performance for various information sharing under lost sale and backorder situations is carried out using the software ‘Supply Chain Role Play Game’. Ten sets of values of total cost, their average value and Standard Deviation (SD) obtained for different cases of information sharing under lost sale and backorder situations are provided in the Table 5.3 and 5.4 respectively. The SD is seen to vary from 5.12 to 10% of the mean under back order and 8 to 14.5% (except for CDPP-19.1%) of the mean under lost sale. Detailed analysis shows that almost 80 to 90% of total cost values (except one or two out of ten just above or below the range) against all information sharing under both lost sale and backorder are within one standard deviation. The details mentioned above regarding SD with respect to mean and each cost values seem to be within the acceptable range since it is a manual simulation rather than computer based simulation. Due to the above reasons, with some caution, for all practical purposes the mean may be taken as performance measure. Therefore the change in performance from one case to the next case of use of coordination can be judged from change in mean profit figures of each case. Hence the results given henceforth only mean is shown. The variation of total cost with type of information sharing under lost sale and backorder situations is shown in Figure 5.3 and 5.4 respectively. As mentioned earlier, the total cost is considered as the overall performance measure of SC in this study.

The average values of total cost corresponding to different information sharing given in Table 5.3 & 5.4 are found different for different information sharing. The best overall performance (minimum cost) is obtained for D&SCP and the lowest performance (maximum cost) is for TDL case under both the situations of the four stage serial SC considered in this study. The variation in average values of total cost with different types of information sharing under both the lost sales and backorder situations are shown in Figure 5.3 and 5.4 respectively. The ‘t’ test is used to analyse the statistical significance of the difference found between a pair of overall performance measure (total cost) corresponding to two particular information sharing cases. This analysis is done at 5% level of significance. Before conducting the ‘t test’, ‘Kolmogorov-Smirnov test’ is conducted to ensure the normality of the sample of total cost values for both the cases and found the result as positive. Statistical tests are done using SPSS and the details of these statistical tests are given in Appendix.

Table: 5.3: Total cost vs. different cases of information sharing under lost sales situation

information sharing	Experiment No. & its corresponding values of total cost for each information sharing										Average value of total cost (RS) (std deviation)
	1	2	3	4	5	6	7	8	9	10	
TDL	7430	6152	7329	7255	5925	6956	7137	6636	6546	7540	6890 (554)
ADI	2024	2685	2197	2512	2267	2201	2011	1784	2201	2580	2246 (278)
CDPP	3588	4168	4165	3524	3024	2758	2723	2680	2597	2795	3202 (612)
CDH	2157	2642	2743	2443	2633	2329	2213	2378	2504	2236	2428 (200)
PSDPP	4106	4928	4775	4592	4628	3916	4151	5332	3653	3459	4354 (594)
PSDH	3601	4571	3929	3864	4819	4429	3493	3770	4156	4269	4090 (433)
FDI	3121	2759	3413	4203	4262	3940	4305	3846	4033	3255	3713 (539)
D&SCP	2224	2185	2444	1948	1775	1923	1824	2082	1912	2561	2088 (263)

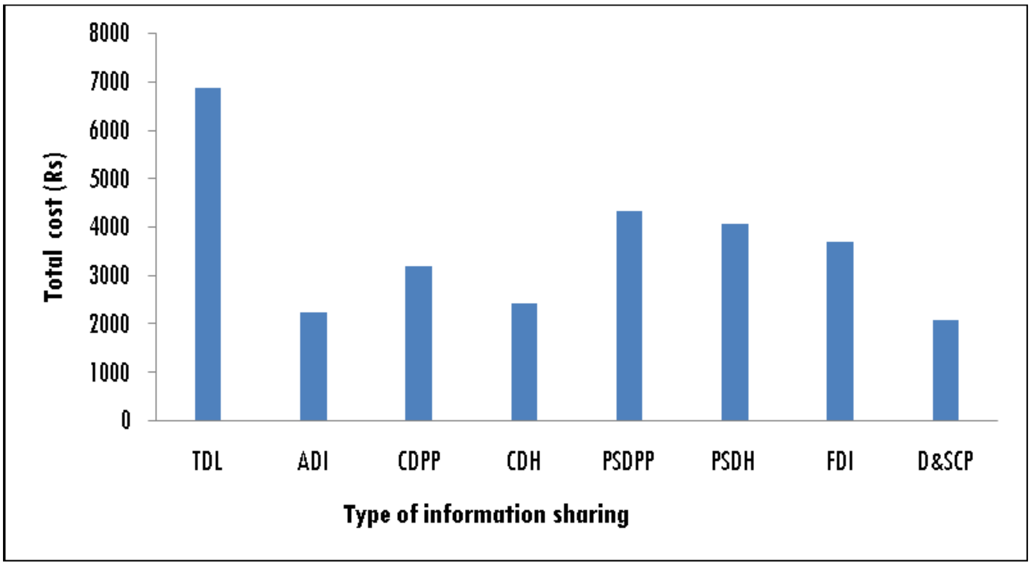

Figure 5.3: Total cost vs. type of information sharing under lost sales situation

Table 5.4: Total cost vs. different cases of information sharing under backorder situation

Type of information sharing	Performance measure	Experiment No. & its corresponding values of total cost (Rs in Lakhs)										Average value of total cost (Std deviation)
		1	2	3	4	5	6	7	8	9	10	
TDL	Total cost (Rs in Lakhs)	21.76	22.74	23.36	26.06	27.08	28.11	27.51	27.35	22.06	24.93	**25.09** (2.44)
ADI		18.45	17.99	18.58	20.23	17.04	16.43	16.55	16.04	16.38	17.52	**17.52** (1.31)
CDPP		19.27	20.73	22.79	21.24	22.52	23.68	18.82	19.36	22.30	23.67	**21.44** (1.83)
CDH		17.91	17.27	18.28	20.66	17.71	18.44	21.02	22.48	22.22	20.93	**19.69** (1.97)
PSDPP		21.39	19.88	20.06	23.15	18.51	24.25	22.84	19.27	23.75	22.77	**21.59** (2.03)
PSDH		19.05	20.71	18.62	19.10	23.28	23.60	23.09	23.74	21.34	22.53	**21.51** (2.02)
FDI		20.16	20.21	20.57	23.75	21.16	23.82	22.64	20.64	21.34	20.42	**21.47** (1.41)
D&SCP		17.20	18.49	16.25	16.88	16.48	16.08	15.93	17.82	17.98	16.64	**16.97** (0.87)

The average values of all the performance measures obtained for each case under lost sale and backorder situations are consolidated and presented in

Table 5.5 and 5.6 respectively. Each of these performance measures (fill rate, bullwhip effect, lost sales cost/backorder cost and total cost) is analysed and ranked according to its magnitude under both situations. This analysis is done to understand the performance of SC with respect to each parameter under each case. Overall analysis showed that "Demand and supply chain performance" (D&SCP) is ranked as the first in almost all cases except in the case of bullwhip effect (ranked as III) and lost sale cost (ranked as II).This indicates that overall performance of supply chain improves as information sharing contains more details. It is also to be noted that the difference between some pair of information sharing such as customer demand per period (CDPP) and customer demand history (CDH), Point of sales data per period (PSDPP) and point of sales data history (PSDH), Advance demand information (ADI) and forecasted demand information sharing (FDIS) is relatively less compared to other pairs. So, the difference in performance corresponding to these cases in each pair also found to be negligible. However, ADI is slightly better than FDI in almost all cases except in the case of bullwhip effect and inventory cost.CDH also performs slightly better than CDPP in most cases. This is due to the reason that lack of recording the demand data by the players in the case of CDPP. The scenario and reason remains same when compare PSDPP and PSDH which is slightly better compared to the other in most cases. It is found that under lost sales situation, the SC fill rate is obtained as nearly 'one' in all the cases of information sharing. In the case of back order situation, fill rate need not be considered as a performance measure as it will be always one (100%) as there is a provision of backorder for any shortage in each period. As far as bullwhip effect is concerned, it is not reduced with information sharing under both lost sale situation and backorder situation. Another important thing to be noted is that bullwhip effect is found to minimum in the case of TDL under both the situation and the maximum in ADI and CDH for lost sale situation and backorder situation respectively. This is not a usual phenomenon for bullwhip effect under information sharing for any SC. This may be due to the fact that the manufacturer (in this case) might have taken over precautions in producing more than the requirement to avoid lost sale cost/ backorder cost. The bullwhip effect need not occur always due to lack of information sharing but also due to the incorrect ordering pattern (ordering behaviour) of any player with small variation in end customer demand at retailer stage. This over cautious ordering behaviour is seen with the upstream player at the top position in the SC, in this case the manufacturer. As far as backorder cost/lost sales cost and inventory cost is concerned, the SC performs well in the case of either D&SCP or ADI where maximum information is shared among the SC partners. Thus, the overall cost is found out as minimum in the case of D& SCP and the second minimum in the case of ADI. All these results show that there must be a trade of between the backorder /lost sales and inventory based on the information obtained for the better performance of an SC.

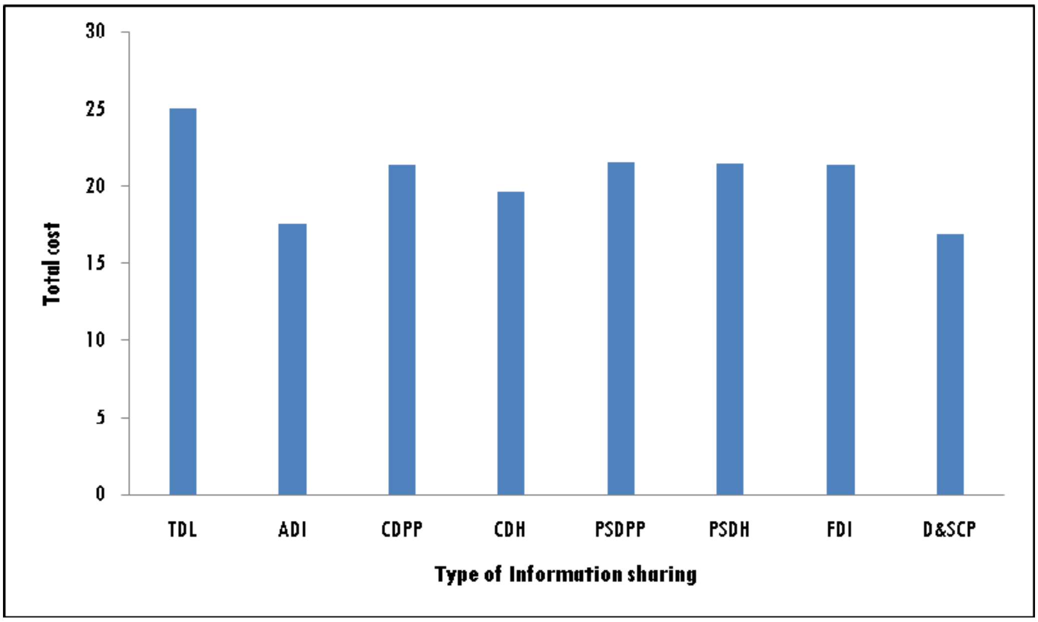

Figure 5.4: Total cost (Rs in Lakhs) vs. type of information sharing under back order situation

Table 5.5: Ranking of Information sharing (IS) cases for different performance measures under lost sale situation

Sl. No.	IS cases	Fill rate (%)	Rank	Bullwhip effect	Rank	Lost sale cost (Rs)	Rank	Inventory cost (Rs)	Rank	Total cost (Rs)	Rank
1	TDL	91.9	VIII	2.94	I	6148	VIII	742	IV	6890	VIII
2	ADI	97.8	II	16.03	VIII	1415	I	831	VII	2246	II
3	CDPP	97.0	IV	8.66	V	2143	IV	1058	VIII	3202	IV
4	CDH	97.5	III	10.84	VII	1689	III	738	III	2428	III
5	PSDPP	95.7	VII	3.88	II	3661	VII	692	II	4354	VII
6	PSDH	96.2	VI	5.27	III	3263	VI	827	VI	4090	VI
7	FDI	96.6	V	5.32	IV	2902	V	811	V	3713	V
8	D&SCP	97.9	I	10.07	VI	1537	II	551	I	2088	I

Table 5.6: Ranking of Information sharing (IS) cases under different performance measures under backorder situation

Sl. No.	IS cases	Bullwhip effect	Rank	Backorder cost (Rs)	Rank	Inventory cost (Rs)	Rank	Total cost(Rs)	Rank
1	TDL	4.94	I	856500	VIII	1652961	VIII	2509461	VIII
2	ADI	11.75	VI	430900	I	1321776	II	1752676	II
3	CDPP	14.45	VII	607300	IV	1537051	VII	2144351	IV
4	CDH	16.5	VIII	515800	II	1453972	V	1969772	III
5	PSDPP	5.23	II	756900	VII	1402378	III	2159278	VII
6	PSDH	5.81	III	645600	V	1505441	VI	2151041	VI
7	FDI	6.91	IV	719100	VI	1428629	IV	2147729	V
8	D&SCP	8.5	V	535000	III	1162935	I	1697935	I

Figure 5.5 shows the improvement in overall performance (total cost) with each information sharing compared to traditional case under two business situations. From this analysis, it is observed that the improvement in overall performance for different information sharing with respect to traditional case is

significantly high in the case of lost sales compared to backorder situation. This shows that information sharing is more beneficial and effective in lost sales situation than backorder situation. This phenomenon is due to the fact that lost sales cost is reduced significantly in the case of D&SCP considering TDL under lost sales situation whereas back order cost is not reduced to that extent in the case of D&SCP considering TDL under backorder situation. The reduction in inventory cost for D&SCP compared to TDL is also more in the case of lost sale situation compared to backorder situations. These observations are obtained from the analysis provided in the Table 5.5 & 5.6. The analysis reveals that the improvement in overall performance (%) obtained by the implementation of information sharing is almost two to three times higher in the case of lost sales than the backorder situation. This difference need not be the same for all the products and it depends on other factors such as demand, lead time and other operating conditions of the SC. But, it can be concluded that information sharing is found to be more effective in lost sales situation in this study.

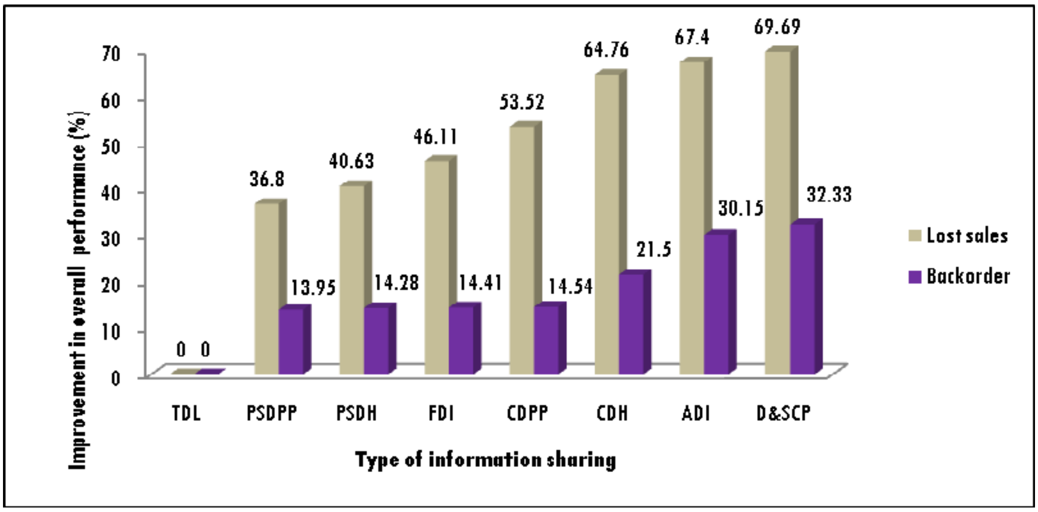

Figure 5.5: Improvement in overall performance under each information sharing compared to the traditional case under lost sale and backorder situations

Table 5.7 and 5.8 show the statistical significance of the difference observed between the two values of total cost (overall performance measure) for a pair of information sharing. This part of the study found that the better performance of D&SCP observed when compared with all other types of information sharing is statistically significant except with ADI. This indicates that the improvement in overall performance in the case of D&SCP compared to other cases can be considered as true with 95% confidence. The analysis also indicates that there does not exist any difference between the total cost values corresponding to D&SCP and ADI and their impact on SC performance is statistically same. As shown in Table 5.7, the‘t’ test results shows that the difference in total cost found between ‘D&SCP’ & ADI, FDI & CDPP, FDI &PSDH, and PSDH & PSDPP under lost sales situation is not statistically significant. It indicates that the impact of the ‘two’ information sharing in each of these pairs on SC performance can be considered as the same with 95% confidence.

Under backorder situation as shown in Table 5.8, the statistical significance of observed difference in total cost values corresponding to a pair of information sharing is almost the same as in lost sale environment except in three out of twenty eight cases. These three cases are PSDPP & FDI, CDPP& PSDPP and CDPP&PSDH (statistical significance found in lost sale case) where no statistical significance is found in backorder case. This is due to the fact that in the case of lost sale, some orders are lost forever whereas in the case of backorder the order is not lost but filled after a delay. The penalty therefore in lost sale case is much more than in backorder case, hence Information sharing shows better results in the case of lost sale, which is visible in the statistical test results. Further, the difference between the amount of information sharing among the two IS cases in a pair of the three mentioned above is relatively negligible compared to other cases. So, the difference in effect will be further less in the case of backorder compared to lost sale and this is the reason due to which it shows no statistical significance for the difference found in the result obtained from the experiment.

Table 5.7: Statistical significance for the difference existing between the overall performance (total cost) corresponding to a pair of different information sharing (IS) under 'lost sale'

IS cases	Total Cost (Rs)	D&SCP	ADI	FDI	CDH	CDPP	PSDH	PSDPP	TDL
		2088	**2246**	**3713**	**2428**	**3202**	**4090**	**4354**	**6890**
D&SCP	2088								
ADI	2246	NO							
FDI	3713	YES	YES						
CDH	2428	YES	YES	YES					
CDPP	3202	YES	YES	NO	YES				
PSDH	4090	YES	YES	NO	YES	YES			
PSDPP	4354	YES	YES	YES	YES	YES	NO		
TDL	6890	YES	YES	YES	YES	YES	YES	YES	

Table 5.8: Statistical significance for the difference existing between the overall performances (total cost) corresponding to a pair of different information sharing (IS) under 'backorder'

IS cases	Total Cost (Rs)	D&SCP	ADI	FDI	CDH	CDPP	PSDH	PSDPP	TDL
		1697935	1752676	2147729	1969772	2144351	2151041	2159278	2509461
D&SCP	1697935								
ADI	1752676	NO							
FDI	2147729	YES	YES						
CDH	1969772	YES	YES	YES					
CDPP	2144351	YES	YES	NO	YES				
PSDH	2151041	YES	YES	NO	YES	NO			
PSDPP	2159278	YES	YES	NO	YES	NO	NO		
TDL	2509461	YES	YES	YES	YES	YES	YES	YES	

5.5 Conclusion

The experimental study conducted to analyze the performance of a four stage serial SC system for different types of information sharing shows that the overall performance can be improved by sharing more details of operating parameters of each player with other players. The total cost which is the sum of inventory cost and backorder cost/lost sales cost is used to measure the overall performance of the SC in this study. Analysis reveals that information sharing enhances the overall performance of the SC and the extent of improvement in performance depends on the type of information shared among SC members. In this study, best performance is obtained with sharing of demand and SC performance with all players and the least performance is with traditional case where only orders are being communicated. Another finding in this study is that bullwhip effect need not occur always only due to the lack of information sharing but also due to incorrect ordering pattern (ordering behavior) of any player with small variation in end customer demand at retailer stage. In this study, manufacturer might have taken over precautions in producing more than the requirement to avoid lost sale cost/backorder cost. This caused high bullwhip effect in the case of ADI (lost sale) and CDH (backorder) even though relatively more details of information has been shared in these two cases.

Detailed analysis on the performance measures obtained in this study includes the ranking of information sharing cases under each performance measure and it will be helpful for the SC practitioners to take appropriate decision in this regard. An appropriate statistical test called 't test' is also conducted to analyse the statistical significance of observed difference between total cost values (overall performance measure) corresponding to a pair of information sharing. The rate of improvement in overall SC performance corresponding to each type of information sharing with respect to traditional case is found out as significantly high in the case of lost sales situation compared to backorder situation. This study is intended to get a clear picture regarding variation in different performance measures with different information sharing under two business situations. The input data used in this study was collected from the concerned industry to provide a realistic situation for the simulation study. The results from this simulation study are to that extent more realistic making the findings practically useful.

Chapter **6**

SUMMARY, CONCLUSION AND SCOPE FOR FUTURE WORK

Contents

6.1 Summary of Work Done

Supply Chain Management (SCM) is a pertinent area for the research especially for those who deal with interdisciplinary areas of management. A detailed study on SCM was conducted as a first step to this research which includes the overall concept of Supply Chain (SC), strategic role and responsibilities of each member in an SC, key drivers and obstacles of SC and various issues of coordination with appropriate methodologies to solve it. This study revealed the importance of supply chain coordination(SCC) without which complete success of SCM cannot be achieved in any industry. Further study on SCM with a special reference to SCC was then conducted as the next step for the in depth analysis. The literature review on SCC revealed various issues still to be addressed. From literature, it was also found that different categories of mechanisms were used to solve some of the SCC issues. Finally, it was decided to concentrate on how to improve the performance of SC by implementing selected coordination mechanisms separately and jointly under various operating conditions of SC. The SCC issues addressed in this study are order quantity, back order, lost sales, inventory, customer service level, bullwhip effect and finally the overall performance indicated by SC profit (surplus)/cost.

After literature review, the topic for research was decided as “study of supply chain coordination and mechanisms to improve its performance”. The research was further focused on the study of the performance of a three level SC consisting of one player at each level (supplier- manufacturer- retailer) facing price dependent demand with price discount and delay in payment simultaneously being used as coordination mechanisms. This study used mathematical modelling. The cost and revenue parameters of each player in the supply chain were formulated and then the profit function of each player was derived. Finally, a mathematical model for the overall profit of the three-level SC was developed. The data obtained from a standard problem in literature was used to solve the model using ‘Excel solver’. Sensitivity analysis was also conducted. The results showed that the performance of SC (SC profit) increases significantly on implementing the coordination mechanisms simultaneously, as against the individual case of ‘price discount alone’ and ‘no coordination’.

The three level SC considered in mathematical modelling was then extended to a three level networked SC consisting of four retailers, two wholesalers, and a manufacturer with an infinite parts supplier. The customer demand and lead time were made probabilistic in this part of the study. Price discount and delay in payment are used as coordination mechanisms as in mathematical modelling. The combined and individual effect of price discount, delay in payment on the performance of this network SC under lost sale and backorder cases were studied using simulation modelling. Two separate products were taken for the study under lost sale and backorder. The input data for this study was obtained from the industry to make the study a realistic one. The simulation modelling was done using the simulation software “Arena”. The simulation was run for each case of ‘no coordination’ (no coordination mechanisms are used) and ‘coordination’ (using ‘price discount’ and ‘delay in payment’ as coordination mechanisms separately and jointly). The simulation results showed that the SC performance (profit) significantly improved in each case of coordination in the individual case of price discount and delay in payment compared to ‘no coordination’. The profit increased further in the case of combination of price discount and delay in payment. A sensitivity analysis was also conducted as a part of this study.

In continuation of the above, a study on the performance of a four- level SC consisting of a manufacturer, a wholesaler, a distributor and a retailer with ‘information sharing’ as coordination mechanism under lost sale and backorder cases using a simulation game with live players was conducted. This simulation study was conducted using software called ‘Supply Chain Role Play Game’ (SCRPG) developed at NIT, Calicut by Pamulety and Pillai (2010). This simulation game was conducted with the help of a group of well trained students having knowledge of SCM who performed the role of each player in the SC and played using a network of five computers including the server system. Experiments were conducted using the simulation game with different types of information sharing cases such as traditional method, point of sales data, forecast demand, actual customer demand, demand and supply chain performance (latest period demand, latest period demand met, latest period inventory of each stage, and order quantity). The results show that the maximum SC performance is obtained while sharing ‘demand and supply chain performance (D&SCP)’ and the minimum under ‘traditional’ way of doing business. As part of this study, statistical tests were also conducted to analyse the statistical significance of the difference found between the performances of SC corresponding to various types of information sharing.

6.2 Limitations of the Study

This research work is conducted to study the performance of a multi-level SC using selected coordination mechanisms under dynamic operating conditions. The input data also were collected from the industry to make the study a realistic one to the extent possible. But, the models used were having many constraints which move them away from reality to some extent. The following limitations are listed out as far as this study is concerned.

- Limited to a four level SC with maximum four players at a level
- Limited to certain types of information sharing (IS)
- Uncertainty is limited to demand and lead time
- Limited to two category of mechanisms (supply chain contracts & IS)
- Sourcing &logistic part are not considered
- All revenue/costs items are not considered
- Production & storage capacity constraints are not considered
- Single product case only considered
- Profit/ cost only was used to measure performance

6.3 Major Findings and Discussion

The study on the performance of three-level SC with price discount and delay in payment jointly as coordination mechanisms using mathematical modelling was conducted for various cases of delay in payment as follows. i) permissible delay in payment is maximum up to buyer's inventory cycle time and no extension allowed ii) delay in payment availed by the buyer (with interest for the additional period that exceeds the permitted one) is greater than the permissible delay in payment but both (permissible and availed) are maximum up to buyer's inventory cycle time iii) delay in payment availed by the buyer (with interest for the additional period that exceeds the permitted one) is greater than or equal to and permissible delay in payment is less than or equal to, the buyer's inventory cycle time. The analysis showed that the SC profit increases in the second case compared to the first case and further increases in the third case compared to the second case. It is found that the reason for this increase in profit in second case and further increase in third case (where the delay in payment availed is more than the inventory cycle time) is as follows i) the reduction net inventory carrying cost due to both reduction in holding cost and increase in end customer demand since the demand is price elastic ii) the increase in net savings due to more time and money available for investment due to the increase in inventory cycle time. The amount of increase in profit in the second and the third case is 0.12% and 0.51% respectively. So, the third case is used for the rest of the analysis in this part of the study. The SC profit increases while using 'price discount' alone compared to 'no coordination' and further increased when using 'price discount' & 'delay in payment' jointly compared to price discount alone. The results showed that the amount of increase in SC profit in the case of 'price discount' alone and combination of 'price discount' and 'delay in payment' is 1.44% and 2.49% respectively compared to 'no coordination'. Another important finding is that the optimal value of interest free permissible delay in payment permitted by the supplier to the manufacturer is obtained as zero in the second and third case as supplier does not get any delay in payment from its upstream player in this study which affects the supplier in second and third case. The optimal value of price discount is obtained as minimum (zero) for supplier and maximum (20.61) for retailer in the third case (maximum SC profit case). The reasons for these results are also same as above i.e., supplier is not getting any discount from its upstream player and the discount given by the retailer decides the end customer demand respectively. Sensitivity analysis revealed the effect of various system parameters on SC profit. The analysis showed that the effect of the rate of return of manufacturer affects the SC profit more, compared to other players in this study. This is because the manufacturer is getting the chance to invest the amount to be paid to the supplier and at the same time to receive the interest from the retailer for delaying the payment. But, the retailer has no opportunity to get the interest due to delay in payment from its downstream player even though he has the opportunity to invest the amount to be paid to the manufacturer and Similarly, supplier has the opportunity to receive the interest from the manufacturer but no opportunity to delay the payment to its upstream player and to make the investment. Sensitivity analysis also showed that the order cost of retailer plays a major role on the SC profit as it is very crucial in deciding the order quantity of other players in this study. As price elasticity increases, the SC profit in the case of combination of 'price discount' and delay in 'payment' increases compared to the case of 'price discount' alone but the rate decreases. This shows that the effect of a combination of these mechanisms on SC profit is relatively less at higher elasticity of demand.

The results obtained from the simulation of network SC for various cases of coordination and no coordination show that the SC profit enhanced significantly due to coordination under both lost sale and backorder cases. The Standard Deviation (SD) of the profit values obtained from the 20 simulation runs is seen to vary from 0.3 to 0.7 % of the mean. The SD being so small implies that, for all practical purposes the mean has been taken as the performance measure. Therefore the change in performance from one case to the next case of use of coordination could be judged from change in mean profit figures of each case. The maximum increase in profit is found in the case of a combination of price discount and delay in payment under both lost sale (10.01%) and backorder (7.85%) compared to 'no coordination'. The increase in SC profit in the case of price discount and delay in payment is 2.10% and 6.53% respectively under lost sale compared to ‘no coordination’. Similarly, the increase in profit in the case of price discount, delay in payment is 3.09%, 4.06% respectively under backorder compared to ‘no coordination’. It is also found that increase in SC profit is relatively high in the case of ‘delay in payment’ compared to the case of price discounts under both the cases. This is due to the decrease in total order cost of each player because of increase in order quantity of the retailer and others as well due to reduction in holding cost in the case of delay in payment compared to other mechanism. This improvement in performance in the individual case of ‘delay in payment’ compared to price discount alone cannot be generalized as the performance of price discount depends on the price elasticity of demand also. The in-depth analysis shows that the manufacturer profit (the upstream player in the network SC) is reduced, compared to others owing to coordination, especially in the case of price discount alone. This is due to the fact that the manufacturer is not getting any discount or delay in payment from his upstream player and the manufacturer sacrifices for the overall benefit of SC. Since the overall SC profit increases owing to coordination, the decrease in profit for the manufacturer under coordination can be compensated by proper profit sharing methodology among players to get equal rate of return for each player based on their investment. The analysis also showed that individual hike in profit in the case of the wholesaler and the retailer due to coordination is significantly high under both lost sale and backorder. It is also found that the increase in profit for various cases of coordination is high in the case of lost sale compared to backorder. So, the effect of ‘delay in payment’ and combination of ‘price discount’ and ‘delay in payment’ on SC profit is relatively high in the case of lost sale as the amount of reduction in cost is relatively high compared to backorder.

It is seen from the sensitivity analysis that Rs.3 and Rs.3000 are the optimal value of ‘price discount’ under lost sale and backorder respectively in the case used in this study. Sensitivity analysis also showed that there is a proportional change in SC profit with change in rate of return of any player. Therefore, the rate of return should be kept at the highest possible level by each player. The in-depth analysis revealed that the rate of return of the wholesaler and the retailer affects more on SC profit, compared to the manufacturer under lost sale and under backorder. The sensitivity analysis on price elasticity showed that the SC profit is increasing with a rise in price elasticity and the rate of increase in profit is almost constant for both lost sale and backorder cases. However, it is found that the rate of increase in SC profit is consistently higher in backorder case. The analysis on various cases of order cost showed that the mutual interchange of order cost between the wholesaler and the manufacturer does not make any change in SC profit, provided order cost of retailer remains same. It is also found that when the order cost of the retailer is reduced, the optimum value of discount is also reduced and it remains same in all other cases. The overall analysis on order cost showed that the order cost of the retailer plays a major role, as it decides the order quantity of the retailers and other players in this study. These findings on order cost are the same under both lost sale ad backorder cases. Sensitivity analysis on delay in payment revealed that change in permissible delay in payment given by the manufacturer to the wholesaler affects SC profit more, compared to the change in permissible delay in payment given by the wholesaler to the retailer in this study. It is also found that the change in delay in payment availed by the wholesaler from the manufacturer affects SC profit more, compared to the change in delay in payment availed by the retailer from the wholesaler. Another finding on delay in payment is that the change in permissible delay in payment given by the seller to the buyer affects SC profit more than the delay in payment availed by the buyer from the seller. However, the maximum profit is obtained when the permissible delay in payment is zero and delay payment that can be availed by the buyer from the seller is the maximum which is taken as buyer's inventory cycle time in this study. The consolidated comparative statement of the effect of different cases of ‘coordination’ and ‘no coordination’ under lost sale and backorder provides an overall idea about how one coordination mechanism performs compared to the other and ‘no coordination’.

The study of the performance of a four - level SC with ‘information sharing’ as coordination mechanism using Simulation software called ‘Supply Chain Role Play Game’ (SCRPG) revealed the following. The overall performance of SC is improved due to information sharing. The SD is seen to vary from 5.12 to 10% of the mean under back order and 8 to 14.5% (except for CDPP-19.1%) of the mean under lost sale. Detailed analysis shows that almost 80 to 90% of total cost values (except one or two out of ten just above or below the range) against all information sharing under both lost sale and backorder are within one standard deviation. The details mentioned above regarding SD with respect to mean and each cost values seem to be within the acceptable range since it is a manual simulation rather than computer based simulation. Due to the above reasons, with some caution, for all practical purposes the mean may be taken as performance measure. The improvement in overall performance compared to traditional case in the case of sharing demand and supply chain performance(D&SCP) is found to be 70% , and 36% in the case of sharing point of sales data per period (PSDPP, the case in which minimum improvement is obtained) compared to traditional case in the case of ‘lost sale’. In the case of backorder, it is 33% and 14% in the case of D&SCP and PSDPP respectively compared to ‘no coordination’. It is also found that the effect of information sharing is more effective in the case of lost sale compared to backorder. This phenomenon is due to the fact that lost sales cost decreases significantly in the case of D&SCP considering TDL under lost sales situation whereas back order cost does not decrease to that extent in the case of D&SCP considering TDL under backorder situation. The reduction in inventory cost for D&SCP compared to TDL is also more in the case of lost sale situation compared to backorder situations. Overall analysis showed that “Demand and supply chain performance” (D&SCP) is ranked as the first in almost all cases except in the case of bullwhip effect (ranked as III) and lost sale cost (ranked as II). This indicates that overall performance of supply chain improves as information sharing contains more details. It is also to be noted that the difference between some pair of information sharing such as customer demand per period (CDPP) and customer demand history (CDH), Point of sales data per period (PSDPP) and point of sales data history (PSDH), Advance demand information (ADI) and forecasted demand information sharing (FDIS) is relatively less compared to other pairs. So, the difference in performance corresponding to these cases in each pair also found to be negligible. However, ADI is slightly better than FDI in almost all cases except in the case of bullwhip effect and inventory cost.CDH also performs slightly better than CDPP in most cases. This is due to the reason that lack of recording the demand data by the players in the case of CDPP. The scenario and reason remains same when compare PSDPP and PSDH which is slightly better compared to the other in most cases. It is found that under lost sales situation, the SC fill rate is obtained as nearly ‘one’ in all the cases of information sharing. In the case of back order situation, fill rate need not be considered as a performance measure as it will be always one (100%) as there is a provision of backorder for any shortage in each period. As far as bullwhip effect is concerned, it is not reduced with information sharing under both lost sale situation and backorder situation. Another unexpected finding in this study was that bullwhip effect is not reduced in the case of D&SCP in which best overall performance (minimum cost) is obtained and bullwhip effect is found to be minimum in the traditional case in which least overall performance (maximum cost) is obtained. The in-depth analysis in this study showed that the last upstream player (manufacturer in this case) might have taken over precautions in placing the ordered quantity to avoid inventory cost or lost sale cost/ backorder cost. The bullwhip effect need not occur always due to lack of information sharing but also due to the incorrect ordering pattern of the last upstream player even with small variation in customer demand at retailer stage. So, it can be concluded that the lack of information sharing either produces bullwhip effect causing large inventory cost or backorder cost/lost sales cost for the extreme last player depending upon the approach of them.

The ‘t test’ proved that the difference found between the overall performance corresponding to a pair of information sharing is statistically significant.

6.4 Conclusion

The study on the performance of three-level SC using mathematical modelling and network SC using simulation modelling with price discounts and delay in payments as coordination mechanism revealed that the SC performance is significantly improved due to combination of mechanisms compared to individual cases as well as no coordination. So, combination of mechanisms can be tried to improve the SC performance considering all practical aspects. Sensitivity analysis in both the studies revealed that retailer has major role as it decides the order quantity of other players in the operating environment we have considered for our study. It is also found that the state (rate of return) of middle player affects more on SC profit. In the case of mathematical modelling and analysis, it revealed that SC profit becomes the maximum in the case where the delay in payment period availed by the buyer from the seller exceeds the buyer’s inventory cycle time. The rate of improvement in performance in the case of a combination of coordination mechanisms studied in comparing with the case of ‘price discount’ alone was found to be decreasing with an increase in price elasticity of demand.

Simulation modelling with price discount and delay in payment under lost sale and backorder revealed that the combination of these mechanisms are more effective in the case of lost sale compared to the other. Sensitivity analysis of this part of the study also shows the delay in payment between manufacturer and wholesaler affects more than the delay in payment between wholesaler and retailer. It is also noted that the increase in permissible delay in payment given by the up steam players and the decrease in delay in payment availed by the downstream players reduces the SC profit and maximum profit is obtained when the permissible delay in payment availed by the downstream payers is equal to the buyer's inventory cycle time (maximum delay in payment permitted in this study considering the practice in industry) and the delay in payment given by the upstream players is equal to zero. The comparative statement of increase in profit with each other will help the practitioners to take appropriate decisions considering the effort required and other practical aspects of implementing the same.

In this study, overall sensitivity analysis revealed that order cost of retailer, rate of return of retailer & wholesaler, permissible delay in payment given by the manufacturer to the wholesaler, price elasticity of demand and the business case in which the system works (lost sale or backorder) play a major role in SC profit. These being specific cases, the numerical results obtained are not directly applicable to other cases. However, the general trends and more so, the methodology followed for the sensitivity analysis, may be used to gain insights regarding the effect of changes in decision variables on SC profit.

The experimental study conducted to analyze the performance of a four stage serial SC system with different types of information sharing using simulation game with live players concluded that the overall performance can be improved by sharing more details of operating parameters of each player with other players. Analysis revealed that information sharing enhances the overall performance of the SC and the extent of improvement in performance depends on the type of information shared among SC members. In this study, the best performance is obtained with sharing of demand and SC performance (D&SCP) with all players and the least performance is with traditional case where only orders are being communicated. While concluding it is also to be noted that the unusual phenomenon of huge bullwhip effect happened in the case of information sharing where relatively best overall performance is obtained in this study. The reason we have found out for this incident is that large variation in ordering pattern of top upstream player without considering the small variation in end customer demand.

Ranking of different types of information sharing based on the various performance measures helped to understand its performance under various cases. Statistical test conducted in this part of the study provided a scientific support for the same. The rate of improvement in the overall SC performance corresponding to each type of information sharing with respect to traditional case is found out as significantly high in the case of lost sales situation compared to backorder situation. It shows that information sharing is more effective in the case of lost sales. Further to this, an element of human psychological effect was also involved in this study as students acted the role of each player which makes the study more realistic. So, it is expected that the results from this simulation study are more realistic to an extent, making the findings practically useful.

6.5 Scope for Future Work

The studies conducted as part of this research work can be straightaway extended to more realistic SC's consisting of more number of levels and more players at each level with dynamic operating conditions. In this study, only two categories of mechanisms (supply chain contracts and information sharing) are used to coordinate the SC, thereby to improve the performance. There are a number of coordination mechanisms other than price discounts and delay in payments (supply chain contracts) and information sharing cases used in this study. Some of the other mechanisms found in the literature under supply chain contracts are buyback, revenue sharing, and quantity flexibility contracts, etc. Under information sharing, mechanisms such as sharing of production schedule, cost sharing, sharing of marketing campaigning and advertisement programs, etc. are included. Apart from these, Information Technology (IT) and joint decision making are other categories of mechanisms available in the literature which can also be used to coordinate the SC and to analyze the improvement in performance. Under Information Technology, effect of use of Electronic Data Interchange (EDI), B2B e-Commerce etc may be studied. Joint decision making on replenishment, forecasting, ordering, cost aspects, etc. are some of the mechanisms under this category. Joint decision making on ordering quantity was also used along with price discount and delay payment in the simulation modelling of our study. All the mechanisms mentioned above can be used individually and jointly to analyse their effect on SC performance and such a study will be certainly relevant and useful to the SC practitioners.

In addition to the above, we have used only the case of a single product throughout our study. So, this study can be extended to a case of multiproduct. As far as operational parameters are concerned, fuzziness, capacity constraints, etc. can also be incorporated in the future study. In the present competitive and dynamic business environment, the concept of an agile supply chain is very important. So, the aspect of agility in an SC can also be made part of the scope for future work. It is certain that studies incorporating all these factors mentioned above will make further realistic in all aspects.

Sourcing, logistics, disruptions and effective use of IT are not considered in this study and these are some of the other important areas need to be addressed further to make the study completely helpful for the SC practicing community. As all these areas are vast and highly relevant, each one can be separately studied to solve the related issues to make a successful SC.

The mechanisms or issues we have so far discussed are quantitative in nature. Qualitative issues or mechanisms, such as behaviour, trust, ethics and satisfaction among players and customers are also very important for the long term success of SCM and to effectively implement the above mentioned mechanisms.

A detailed study of simulation modelling and analysis for various SC coordination issues under dynamic operating conditions using different categories of mechanisms and quantifying the value of the same will be helpful for the SC practitioners to select and implement the appropriate mechanism properly for a successful Supply Chain Management of a particular case. Performance measures other than Profit/Cost could also be used to broaden the study.

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Abu-Suleiman, A., Boardman, B. & Priest, J. W.(2004). 'A Framework for an Integrated Supply Chain Performance Management System,' *Industrial Engineering Research Conference*, Houston, TX.

Agami, N., Saleh, M. and Rasmy, M.(2012), ' Supply Chain Performance Measurement Approaches: Review and Classification', *Journal of Organizational Management Studies,* Vol.2012, pp.1-20.

Agrawal, S., Sengupta, R.N. and Shanker, K. (2009), 'Impact of information sharing and lead time on bullwhip effect and on-hand inventory', *European Journal of Operational Research*, Vol.192, pp.576-593

Ahmed M.A E.I Saadany and Jaber, M.Y. (2008),'Coordinating a two-level supply chain with production interruptions to restore process quality', *Computers & Industrial Engineering,* Vol. 54, pp.95-109

Alitok, T. and Melamed,B.(2007), 'Simulation Modeling and analysis with Arena' Elsevier.

Arshinder, Kanda, A. and Deshmukh, S.G (2008), 'Supply chain coordination: Perspectives, empirical studies and research directions', *International Journal of Production Economics*, Vol.115, pp.16-335

Banerjee, A., Kim, S-L. and Jonathan Burton, J. (2007), 'Supply chain coordination through effective multi-stage inventory linkages in a JIT environment', *International Journal of Production Economics,* Vol.108, pp.271-280

Bottani, E., Ferretti, G., Montanari, R. and Vignali, G. (2012), 'The impact of (S, s) policy on supply network performance: a simulation study', *International Journal of Business Performance and SC Modeling*, Vol.4, No.2, pp.164-201.

Brewer, P. C. & Speh, T. W. (2000). 'Using the Balanced Scorecard to Measure Supply Chain Performance,' *International Journal of Business Logistics*, 21(1), 75-93

Byrne, P.J. and Heavy, C. (2006) 'The impact of information sharing and forecasting in capacitated industrial SCs: A case study', *International journal of Production Economics,* Vol.103, No.1, pp.420-437.

Cachon, G. P. and Fisher, M. (2000) 'SC inventory management and the value of shared information', Management *Science*, Vol.46, No.8, 1032-1048.

Cai, G., Zhang, Z.G. and Zhang, M. (2009), 'Game theoretical perspectives on dual – channel supply chain competition with price discounts and pricing schemes', *International Journal of Production Economics*, Vol.117, pp.80-96

Cavinato, J.L., (1992). 'Total cost value model for supply chain competitiveness', *Journal of Business Logistics,* 13(2), 285–291.

Chaharsooghi, K.S. and Heydari, J. (2010), 'Supply chain coordination for the joint determination of order quantity and reorder point using credit option', *European Journal of Operational Research*, Vol.204, pp.86-95

Chan, F.T.S. and Chan, H.K. (2009), 'Effect of cascade information sharing in inventory and service level in multi-echelon SCs', *International Journal of Business Performance and SC Modelling*, Vol.1, pp.1-7

Chang, Y. and Makatsoris, H. (2001), 'Supply Chain Modeling using Simulation', *International Journal of Simulation* Vol.2, No.1, pp. 24-30.

Chen, F., Zvi, D., Jennifer, R. and David, S.(2000) 'Quantifying the bullwhip effect in a simple SC: The impact of forecasting, lead times and information' *Management Science*, Vol.46, No.3, pp.436-443.

Chen, H., Chen, J. and Chen, Y. (2006), 'A coordination mechanism for a SC with demand information updating', *International journal of Production Economics*, Vol.103, pp.347-361

Chen, J. (2013), 'The impact of sharing customer returns information in a SC with and without a buyback policy', *European Journal of Operational Research*, Vol.213, No.3, pp.478-488

Chen, K. and Xiao, T. (2009), 'Demand disruption and coordination of the supply chain with a dominant retailer', *European Journal of Operational Research*, Vol.197, pp.225-234

Chen, L-H and Kang, F-S.(2010),Coordination between vendor and buyer considering trade credit and items of imperfect quality, International Journal of Economics, 123, 52-61

Chen, L-H. and Kang, F-S.(2007), 'Integrated vendor-buyer cooperative inventory models with Variant permissible delay in payments', *European Journal of Operational Research*, 183, 658-673

Chopra S. and Meindl, P. (2004), Supply Chain Management, Pearson Education

Chu, C-L.and Leon, V.J. (2008),' Power-of–two single–warehouse multi-buyer inventory coordination with private information, Vol.111, pp.562-574

Chung, C.J. and Wee, H.M.(2007), 'Optimizing the economic lot size of a three-stage supply chain with backordering derived without derivatives', *European Journal of Operational Research,* Vol.183, pp.933-943

Ding, D. and Chen, J. (2008), 'Coordinating a three level supply chain with flexible return policies', *Omega,* Vol.36, pp.865-876

Dong, W. C. and Lee, Y.H.(2013), 'The value of information sharing in a SC with a seasonal demand process', *Computers & Industrial Engineering*, Vol.65, pp.97-108

Ellis, S.C., Henry, R.M. and Shockley, J.(2010), 'Buyer perceptions of supply disruption risk : A behavioral view and empirical assessment', *Journal of Operations Management* , Vol.28, pp.34-46

Esmaeili, M. and Zeephongsekul, P.(2010), Seller-buyer models of supply chain management with an asymmetric information structure, *International journal of production Economics*, Vol.123, pp.146-154

Fin, B. and Oklahoma, (2006), 'Performance implications of information technology implementation in an apparel supply chain', *Supply Chain Management: An International Journal,* Vol.11/4, pp.309-316

Ganesh, M., Raghunathan, S. and Rajendran, C. (2008), 'The value of information sharing in a multi-product supply chain with product substitution', *IIE Transactions*, Vol.40, pp.1124-1140

Gaudreault, J., Frayret, J-M and Pesant, G. (2009), 'Distributed search for supply chain coordination', *Computers in Industry*, Vol. 60, pp.441-451

Gavirneni, S. (2006), 'Price fluctuations, information sharing, and supply chain performance', *European Journal of Operational Research*, Vol.174, pp.1651-1663.

Gunasekaran, A., Patel, C. & McGaughey, R. E.(2004). 'A Framework for Supply Chain Performance Measurement,' *International Journal of Production Economics*, 87(3), 333-347.

Hendricks, K.B., Singhal, V.R. and Stratman, J.K. (2007), 'The impact of enterprise systems on corporate performance: A study of ERP, SCM, and CRM system implementations', *Journal of Operations Management*, Vol.25, pp.65-82

Hendricks, K.B., Singhal, V.R. and Zhang, R. (2009), 'The effect of operational slack, diversification, and vertical relatedness on the stock market reaction to supply chain disruptions', *Journal of Operations Management*, Vol.27, pp.233-246

Ho, C-H., Ouyang, L-Y. and Su, C-H.(2008), 'Optimal pricing, shipment and payment policy for an integrated supplier-buyer inventory model with two-part trade credit', *European Journal of Operational Research,* Vol.187, pp.496-510

Hsieh, C-C., Liu, Y-T and Wang, W-M.(2010), Coordinating ordering and pricing decisions in a two-stage distribution system with price-sensitive demand through short-term discounting, *European Journal of Operational Research*, Vol.207, pp.142-151

Hsu, P-H., Teng, H-M., Jou,Y-T and Wee, H.M. (2008), 'Coordinated ordering decisions for products with short lifecycle and variable selling price', *Computers & Industrial Engineering* , Vol.54, pp.602-612

Huang, S. H., Sheoran, S. K. & Wang, G. (2004),"A Review and Analysis of Supply Chain Operations Reference (SCOR) Model," *Supply Chain Management: An International Journal*, 9(1), 23 – 29.

Ingalls, R.G., Rossetti, M.D. and Peters, B.A. (2004), 'Ideas for Modelling and simulation of supply chains with Arena', *Proceedings of the 2004 Winter Simulation Conference*.

Jaber, M.Y. and Goyal, S.K, (2009), 'A basic model for coordinating a four-level supply chain of a product with a vendor, multiple buyers and tier-1 and tier-2 suppliers', *International Journal of Production Research*, Vol. 47, No 13, 3691-3704

Jaber, M.Y. and Osman, I.H. (2006[b]), 'Coordinating a two-level supply chain with delay in payments and profit sharing' , *Computers & Industrial Engineering*, Vol.50, pp.385-400

Jaber, M.Y., Bonney, M. and Guiffrida, A.L. (2010), 'Coordinating a three level supply chain with learning based continuous improvement', *International journal of production economics*, Vol.127, pp.27-38

Jaber, M.Y., Osman, I.H. and Guiffrida, A.L. (2006[a]), 'Coordinating a three level supply chain with price discounts , price dependent demand, and profit sharing', *International Journal of Integrated Supply management* Vol.2 , 28-48

Jain, S. and Ervin, E. (2005), 'Evaluation of SC business process improvements using simulation', *International Journal of Simulation and Process Modelling*', Vol.1, No.3/4, pp.138-149

Johansson, B., Jain, S., Montoya-Torres J. Hugan., and Yucesan, E. (2010), 'Using simulation optimization as a decision support tool for supply chain coordination contracts' *Proceedings of the winter simulation conference,* pp. 1-12

Jonsson, P. and Mattsson, S.(2013) 'The value of sharing planning information in SCs', *International Journal of physical Distribution & Logistics Management*, Vol.43, No.4, pp.282-299.

Kaplan, R. S. & Bruns, W. (1987). 'Accounting and Management: A Field Study Perspective,' *Harvard Business School Press.*

Kaplan, R.S., Norton, P.D., (1992), 'The balanced score board a measure that drives performance', *Harvard Business Review* 70 (1), 71–79.

Karabat1, S. and Say1n, S. (2008), 'Single-supplier/Multiple buyer supply chain coordination: incorporating buyer's expectations under vertical information sharing', *European Journal of Operational Research*, Vol.187, pp.746-764

Kayank, H. and Carr, A. S. (2012) 'The role of information sharing and coordination in managing SC relationships', *International Journal of Integrated Supply Management*, Vol.7, .No.4, pp-246-271

Kelle, P., Miller, P.A. and Akbulut, A.Y. (2007), 'Coordinating ordering/ shipment policy for buyer and supplier: Numerical and empirical analysis of influencing factors', *International Journal of Production Economics,* Vol.108, pp.100-110

Kelle,P., Transchel, S. and Minner, S. (2009), 'Buyer-supplier cooperation and negotiation support with random yield consideration', *International Journal of Production Economics*, Vol.118, pp.152-159

Kelton, W.D., Sadowski, R.P. and Sadowski, D.A. (2001), 'Simulation with Arena' McGraw Hill

Klimov, R and Merkuryev, Y. (2008), Simulation model for supply chain reliability evaluation" *Technological and Economic development of Economy: Baltic Journal on sustainability,* No.14 (3), pp.300-311.

Koh.S.C.L ., Gunasekaran, A. and Rajkumar, D. (2008), 'ERP II: The involvement, benefits and impediments of collaborative information sharing', *International Journal of Production Economics* , Vol.113, pp.245-268

Kuhal,M.E., Steiger, N.M.,Armstrong, F.B., and Joines,J.A.,(2005), " A conceptual model for the creation of supply chain simulation models", *Proceedings of the winter simulation conference*, pp.2619-2627.

Lai, K-H., Christina, W.Y., Wong, T.C. and Cheng, E. (2006), 'Institutional isomorphism and the adoption of information technology for supply chain management', *Computers in Industry,* Vol.57, pp.93-98

Lapide, L. (2000). 'What about Measuring Supply Chain Performance?,' *AMR Research,ASCET - White Paper*, 2(15), 287-297.

Larsen, S.T.(2000), 'European logistics beyond 2000', *International Journal of Physical Distribution Logistics Management*, Vol. 30(6), 377–387

Lau, A.H.L., Lau, H-S. and Wang, J-C. (2007), 'pricing and volume discounting for a dominant retailer with uncertain manufacturing cost information', *European Journal of Operational Research*, Vol.183, pp.848-870

Lau, A.H.L., Lau, H-S. and Zhou, Y-W.(2008), 'Quantity discount and handling –charge reduction schemes for a manufacturer supplying numerous heterogeneous retailers', *International Journal of Production Economics,* Vol.113, pp.425-445

Lee, C.H. (2007), 'Coordination on stocking and progressive pricing policies for a supply chain', *International Journal of Production Economics*, Vol.106, pp.307-319

Lee, C.H. and Rhee, B-D.(2007), 'Channel coordination using product returns for a supply chain with stochastic salvage capacity', *European Journal of Operational Research,* Vol.177, pp.214-238

Lee, H.L., Padmanabhan, V. and Whang, S. (1997), 'The Bullwhip Effect in Supply Chains', *Management Review,* Vol. 38, pp.93-102

Lee, H.L., Padmanabhan, V. and Whang, S. (2004), 'Information Distortion in a Supply Chain: The Bullwhip Effect', *Management Science,* Vol. 50, 12, pp.1875-1886

Lee, Y.H., Cho, M.K., Kim, S.J. and Kim, Y.B.(2002), 'supply chain simulation with discrete – continuous combined modelling', *Computers &Industrial Engineering*, Vol.43, 375-392.

Li, J. and Liu, L. (2006), 'Supply chain coordination with quantity discount policy', *International Journal of Production Economics,* Vol.101, pp.89-98

Li, J. and Liu, L. (2008), 'Supply chain coordination with manufacture's limited reserve capacity: An extended newsboy problem', *International Journal of Production Economics*, Vol.112, pp.860-868

Li, X. and Wang, Q.(2007), ' Coordination mechanisms of supply chain systems', *European Journal of Operational Research*, Vol.179, pp.1-16

Lin, L.C. (2009), 'An integrated frame work for the development of radio frequency identification technology in the logistics and supply chain management', *Computers & Industrial Engineering*, Vol.57, pp.832-842

Lockamy III, A. & McCormack, K. (2004), 'Linking SCOR Planning Practices to Supply Chain Performance: An Exploratory Study,' *International Journal of Operations and Production Management*, 24(11-12), 1192-1218.

Lohman, C., Fortuin, L. & Wounters, M. (2004), 'Designing a Performance Measurement System a Case Study,' *European Journal of Operational Research*, 156(2), 267-86.

Luo, J. (2007), 'Buyer-vendor inventory coordination with credit period incentives', *International Journal of Production Economics*, Vol.108, pp.143-152

McClellan, M.(2003), 'Collaborative Manufacturing', St Lucie Press, Delray Beach, FL.

Min, H. and Zhou, G. (2002), 'Supply chain modelling: past, present and future', *Computers and Industrial Engineering,* Vol.43, No.1-2, pp.231-249.

Neely, A., Gregory, M. & Platts, K. (1995) 'Performance Measurement Systems Design: A Literature Review and Research Agenda,' International *Journal of Operations and Productions Management*, 15(4), 80-116.

Netessine, S. and Rudi, N (2006), 'Supply Chain Choice on the Internet', *Management Science*, Vol.52, 6,pp. 844-864

Oke, A. and Gopalakrishnan, M. (2009), 'Managing disruptions in supply chains: A case study of a retail supply chain', *International Journal of Production Economics*, Vol.118, pp.168-174

Paes, G. Phaniraj, N and Anilkumar (2012), 'A flexible framework for supply chain modelling and simulation', *ISIC,* pp.1-8.

Pamulety, C.T. and Pillai, V. M. (2010), 'Evaluating the performance of a multi-Echelon SC', Proc. of the 4th *International conference on 'Advances in Mechanical Engineering'*, September 23-25, 2010, S.V. National Institute of Technology, Surat, Gujarat, India, pp 271-275

Pamulety,C.T. and Pillai,V.M. (2011), 'Impact of information sharing in SC performance', *Communications in Computer and Information Science*, Vol.145, pp.327-332

Persson, F and Jan Olhager, J. (2002), 'Performance simulation of supply chain design", *International Journal of production economics',* Vol.77, No.3, pp.231-245.

Petrovic, D. (2001) 'Simulation of SC behaviour and performance in an uncertain environment', *International Journal of Production Economics,* Vol.71, pp.429-438

Petrovic, D., Xie, Y., Burnham, K. and Petrovic, R. (2008), 'Coordinated control of distribution supply chains in the presence of fuzzy customer demand', *European Journal of Operational Research*, Vol.185, pp.146-158

Pramatari, K. (2007), 'Collaborative supply chain practices and evolving technological approaches', *Supply Chain Management: An International Journal*, Vol.12/3, pp.210-220

Pundoor, G. and Herrmann, J. W. (2006), 'A hierarchical approach to a SC simulation modeling using the SC operations reference model', *International Journal of Simulation and Process Modeling*, Vol.2, pp.124-132

Qi, X.(2007), 'Order splitting with multiple capacitated suppliers , European Journal of Operational Research, Vol.178, pp.421-432

Ryu, K. and Yucesan, E. (2010), 'A fuzzy news vendor approach to supply chain coordination', *European Journal of Operational Research*, Vol.200, pp.421-438

Ryu, S.Tsukishima.T. and Onari, H. (2009), 'A study on evaluation of demand information - sharing methods in supply chain', International *Journal of Production Economics'*, Vol.120, No.1, pp.162-175.

Samaddar, S., Nargundkar, S. and Daley, M.(2006), 'Inter-organizational information sharing: The role of supply network configuration and partner goal congruence', *European Journal of Operational Research, Vol.*174, pp.744-765

Sanders,N.R. (2008), 'Pattern of information technology use: The impact on buyer- supplier coordination and performance', *Journal of Operations Management*, Vol.26 , pp.349-367

Sarkar, A. and Mohapatra, P.K.J. (2009), 'Determining the optimal size of supply base with the consideration of risks of supply disruptions', *International Journal of Production Economics*, Vol.119, pp.122-135

Sarmah.S.P., Acharya, D. and Goyal, S.K.(2007),'Coordination and profit sharing between a manufacturer and a buyer with target profit under credit option', *European Journal of Operational Research,* Vol.182, pp.1469-1478

Savedi, A. and Jain, V.(2012), 'Effect of sharing forecast information on the performance of a SC experiencing disruptions' , *International journal of Logistics systems and Management*, Vol.13, pp.509-524.

Sezen, B. (2008), 'Relative effects of design, integration and information sharing on supply chain performance', *Supply Chain Management: An International Journal*, Vol.13/3, pp.233-240

Shin, H. and Benton, W.C. (2007), 'A quantity discount approach to supply chain coordination', *European Journal of Operational Research*, Vol.180, pp.601-616

Sinha, S. and Sarmah, S.P (2007), 'Supply chain coordination model with insufficient production capacity and option for outsourcing', *Mathematical and Computer Modeling*, vol.46, pp.1442-1452

Sinha, S. and Sarmah, S.P,(2010), 'Single-vendor multi-buyer discount pricing model under stochastic demand environment', *Computers and Industrial Engineering*, Vol.59, pp.945-953

Skipper,J.B. and Hanna,J.B.(2009), 'Minimizing supply chain disruption risk through enhanced flexibility', International Journal of Physical Distribution and & Logistics Management, Vol.39, pp.404-427

Stephens, S. (2001). 'Supply Chain Operations Reference Model Version 5.0: A New Tool to Improve Supply Chain Efficiency and Achieve Best Practice,' *Information Systems Frontiers*, 3(4), 471-476.

Stern, J. M., Stewart, G. B. & Chew, D. H.(1995). "The EVA® Financial Management System," *Journal of Applied Corporate Finance*, 8(2), 32-46.

Sucky, E. (2006), 'A bargaining model with asymmetric information for a single supplier-single buyer problem', *European Journal of Operational Research*, Vol.171, pp.516-535

Swaminathan, J.M., Smith, S.F. and Sadeh, N.M. (1998), 'Modelling supply chain dynamics: A multi agent approach', *Decision Sciences*, No.3, pp.607-632.

Tang, C.S. (2006), 'Robust strategies for mitigating supply chain disruptions', *International Journal of Logistics: Research and Applications,* Vol.9, 1, pp.33-45

Telsang, M.T. (2005), 'Production management', S. Chand & Company Ltd

Thierry, C., Bel, G. and André Thomas, A.(2010), 'The role of modelling and simulation in supply chain management', *SCS M&S Magazine,* Vol.4*,* pp.1-8.

Thonemann, U.W. (2002), 'Improving SC performance by sharing advance demand information', *European Journal of Operational Research*, Vol.142, No.1, pp.81-107

Tsao, Y-C and Sheen, G-J.(2008), Dynamic pricing promotion and replenishment policies for a deteriorating item under permissible delay in payments, *Computers & Operational Research,* Vol.35, pp.3562-3580

Viswanathan,,S,. Widiarta, H. and Piplani, R. (2007) 'Value of information exchange and synchronization in a multi-tier SC', *International Journal of Production Research*, Vol.45, No.21, pp.5057-5074

Wong, W.P. (2009) 'Performance valuation of SC in stochastic environment: using a simulation based DEA framework', *International Journal of Business performance and SC Modeling*, Vol.1,No.2/3, pp.203-228

Wong. W.K., Qi, J. Leung, S.Y.S. (2009), 'Coordinating supply chains with sales rebate contracts and vendor managed inventory', *International Journal of Production Economics*, Vol.120, pp.151-161

Wu,,Y.N. and Cheng, E.T.C.(2008) 'The impact of information sharing in a multiple-echelon SC', *International Journal of Production Economics*, Vol.115, No.1, pp.1-11.

Wu,F., Yeniyurt,S., Kim, D.S. and Cavusgil, T. (2006), 'The impact of information technology on supply chain capabilities and firm performance : A resource-based view'*, Industrial Marketing Management*', Vol.35, pp.493-504

Xiao, T. and Qi, X.(2008), 'Price competition, cost and demand disruptions and coordination of a supply chain with one manufacturer and two competing retailers' , *Omega*, Vol.36, pp.741-753

Xiao, T., Qi, X. and Yu, G. (2007), 'Coordination of supply chain after demand disruptions when retailers compete', *International Journal of Production Economics* , Vol.109, pp.162-179

Xiao, T., Shi, K. and Yang, D.(2010), 'Coordination of a supply chain with consumer return under demand uncertainty', International Journal of production Economics, Vol.124, pp.171-180

Xie, J. and Wei, J.C.(2009), 'Coordinating advertising and pricing in a manufacturer – retailer channel' , *European Journal of Operational Research*, Vol.197, pp.785-791

Xu, L. (2006), 'Supply chain Coordination and Mechanisms: An attribute-based Approach', *Journal of Supply chain management,* Vol.42, pp.4-12

Xu, L. and Beamon, B. (2006), 'Supply Chain Coordination and Cooperation Mechanisms: An Attribute-Based Approach', *The Journal of Supply Chain Management*, Vol. 42(1) pp.4–12

Xu, M., Qi, X., Yu, G. and Zhang, H. (2006), 'Coordinating dyadic supply chains when production costs are disrupted', IIE Transactions, Vol.38, pp.765-775

Xu, R. and Zhai, X. (2009), 'Analysis of supply chain coordination under fuzzy demand in a two -stage supply chain', *Applied Mathematical Modelling*, Vol.xxx, 1-11

Xu, R. and Zhai, X. (2010) 'Analysis of SC coordination under fuzzy demand in a two-stage SC', *Applied Mathematical Modelling*, Vol.34, No.1, pp.129-139

Xu, X. and Zan, H. (2009), 'On Coordination of Supply chain based on information asymmetry of effort level and fuzzy market environment', *Fuzzy inf. Eng,* Vol.1, pp.67-77

Xue, X. Wang, Y. Shen. Q, Yu, X. (2007), 'Coordination mechanisms for construction supply chain management in the Internet environment, *International Journal of Project Management*, Vol.25, pp.150-157

Xue, X., Shen, Q., Tan, Y., Zhang, Y. and Fan, H. (2011) 'Comparing the value of information sharing under different inventory policies in construction SC', *International Journal of Project Management*, Vol.29, No.7, pp.867-876

Yao, D-Q., Yue, X. and Liu, J. (2008), 'Vertical cost information sharing in a supply chain with value-adding retailers', *Omega*, Vol.36, pp.838-851

Yao, Z., Leung, S.C.H. and Lai, K.K. (2008),'Manufacture's revenue –sharing contract and retail competition', *European Journal of Operational Research*, Vol.186, pp.637-651

Yu, H., Sun, C. and Chen, J. (2007), 'Simulating the supply disruptions for the coordinated supply chain', Vol. 16(3), pp.323-335

Yu, H., Zeng, A.Z. and Zhao, L. (2009), 'single or dual sourcing: decision – making in the presence of supply chain disruption risks', *Omega*, Vol.37, pp.788-800

Yue, J., Austin, J., Wang, M-C and Huang, Z. (2006), 'Coordination of cooperative advertising in a two-level supply chain when manufacturer offers discount', *European Journal of Operational Research,* Vol.168, pp.65-85

Zhao, X., Xie, J. and Zhang, W. J. (2002), 'The impact of information sharing and ordering coordination on supply chain performance', *Supply Chain Management: An International Journal*, Vol.7 (1), pp. 24–40

Zhou, H. and Benton, W.C. Jr. (2007), 'Supply chain practice and information sharing', *Journal of Operations Management,* Vol.25, pp.1348-1365

Zhou, Y-W and Wang, S-D.(2009), 'Manufacturer-buyer coordination for newsvendor-type –products with two ordering opportunities and partial backorders, *European Journal of Operational Research,* Vol.198, pp.958- 974

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PUBLICATIONS

The following are the details of publications made out of work presented in this thesis

- Ambilikumar, C.K. and Bhasi, M. (2011), 'Modelling & Analysis of three level Supply Chain Coordination: Price discounts in conjunction with delay in payments as mechanisms', *proceedings of the International Conference on Advances in Supply Chain and Manufacturing Management*, IIT Kharagpur.
- Ambilikumar, C.K., Bhasi, M. and Madhu, G. (2014), 'Supply Chain Coordination: A Review of Mechanisms and Methodologies', *National Seminar on career Opportunities in Logistics and Supply Chain Management*, Vidyabharathi Group of Institutions, Kochi.
- Ambilikumar, C.K., Bhasi, M. and Madhu, G. (2014), 'Supply Chain Coordination: Effect of Information Sharing on the Performance of a Four Stage Serial Supply Chain system under Backorder and Lost sale Situations', *National Seminar on Moulding Managers for Mankind*, School of Management Studies , Kochi.
- Ambilikumar, C.K., and Bhasi, M. (2012), 'A Review paper on recent developments in Supply Chain Coordination', *International Journal of Logistics and Supply Chain Management* 4(1), 55-70.
- Ambilikumar, C.K., Bhasi, M. and Madhu, G. (2015), 'Modelling and analysis of coordination of a three level supply chain with use of price discount along with delay in payment', *International Journal of Business Performance and Supply Chain Modelling*,Vol.7, No.1, pp.71-91

- Ambilikumar, C.K., Bhasi, M. and Madhu, G. 'Effect of Information Sharing on the performance of a four stage serial Supply Chain under backorder and lost sale situations', *International Journal of Supply Chain and Inventory Management* **(*Accepted in February 2015*)**.
- Ambilikumar, C.K., Bhasi, M. and Madhu, G. 'Simulation Modelling and Analysis of a Network Supply Chain Coordination using Price discount along with Delay in payment under Lost sale and Backorder', *International Journal of Advanced Operations Management* ***(Accepted in July 2015)***

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APPENDIX

In this appendix, the results of the 't test' (5% level of significance) is given based on which the statistical significance of the difference observed between the two values of total cost (overall performance measure) for a pair of information sharing is decided for both lost sale situation and backorder situations. The general null hypothesis and alternate hypothesis taken are as follows

't test' for statistical significance

Null hypothesis: There is no difference between the values of total cost corresponding to a particular pair of information sharing

Alternate hypothesis: Total cost value of one information sharing is higher than the other in a pair under consideration

Comparing the p value obtained from t test and assumed significance level, α (5% in this study), we will accept the alternate hypothesis when $p < \alpha$, and do not accept alternate hypothesis when $p > \alpha$. The procedure of't' test followed is same for both lost sale and backorder situation.

Before conducting the't test', 'Kolmogorov-Smirnov test' is conducted to ensure the normality of the sample of total cost values for both the cases and found the result as positive. The result for each case is given below.

Normality test

Null hypothesis: Parent population of total cost sample is normal

Alternate hypothesis: Parent population of total cost sample is not normal

The normality test is also conducted at 5% level of significance

One-Sample Kolmogorov-Smirnov Test for lost sale case

		TDL	ADI	CDPP	CDH	PSDPP	PSDH	FDI	D&SCP
N		10	10	10	10	10	10	10	10
Normal Parameters[a,b]	Mean	6890.60	2246.20	3202.20	2427.80	4354.00	4090.10	3713.70	2087.80
	Std. Deviation	554.189	278.862	612.429	200.521	594.596	433.211	539.951	263.285
Most Extreme Differences	Absolute	.172	.170	.247	.147	.156	.145	.197	.202
	Positive	.121	.170	.247	.131	.134	.145	.137	.202
	Negative	-.172	-.130	-.162	-.147	-.156	-.084	-.197	-.117
Test Statistic		.172	.170	.247	.147	.156	.145	.197	.202
Asymp. Sig. (2-tailed) or (p value)		.200[c,d]	.200[c,d]	.085[c]	.200[c,d]	.200[c,d]	.200[c,d]	.200[c,d]	.200[c,d]

One-Sample Kolmogorov-Smirnov Test for back order									
		TDL	ADI	CDPP	CDH	PSDPP	PSDH	FDI	D&SCP
N		10	10	10	10	10	10	10	10
Normal Parameters[a,b]	Mean	25.0960	17.5210	21.4380	19.6920	21.5870	21.5060	21.4710	16.9750
	Std. Deviation	2.44485	1.30822	1.83069	1.97000	2.03588	2.02461	1.41845	.87273
Most Extreme Differences	Absolute	.191	.171	.181	.237	.219	.193	.237	.149
	Positive	.161	.171	.172	.237	.173	.183	.237	.149
	Negative	-.191	-.129	-.181	-.188	-.219	-.193	-.178	-.134
Test Statistic		.191	.171	.181	.237	.219	.193	.237	.149
Asymp. Sig. (2-tailed) /or (p value)		.200[c,d]	.200[c,d]	.200[c,d]	.116[c]	.189[c]	.200[c,d]	.119[c]	.200[c,d]
a. Test distribution is Normal.									
b. Calculated from data.									
c. Lilliefors Significance Correction.									
d. This is a lower bound of the true significance.									

Since p>0.05, accept null hypothesis for both the cases of lost sale and backorder. So, parent population of the sample of total cost values can be considered as normal. Therefore't test' can be used to analyse the statistical significance of the difference observed between the two values of total cost (overall performance measure) for a pair of information sharing as follows.

Result of t test (α=5%) for lost sale situation

Pair of information sharing		Paired Differences					t	df	Sig. (p value for 1-tailed) *(Limited to 3 decimal places)*
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	TDL - ADI	4644.400	637.990	201.750	4188.010	5100.790	23.021	9	0.000
Pair 2	TDL - CDPP	3688.400	807.430	255.332	3110.799	4266.001	14.446	9	0.000
Pair 3	TDL - CDH	4462.800	686.249	217.011	3971.887	4953.713	20.565	9	0.000
Pair 4	TDL - PSDPP	2536.600	965.095	305.190	1846.213	3226.987	8.312	9	0.000
Pair 5	TDL - PSDH	2800.500	900.918	284.895	2156.022	3444.978	9.830	9	0.000
Pair 6	TDL - FDI	3176.900	826.324	261.306	2585.784	3768.016	12.158	9	0.000
Pair 7	TDL - D&SCP	4802.800	469.396	148.436	4467.014	5138.586	32.356	9	0.000
Pair 8	ADI - CDPP	-956.000	557.703	176.361	-1354.957	-557.043	-5.421	9	0.000
Pair 9	ADI - CDH	-181.600	288.050	91.089	-387.658	24.458	-1.994	9	0.038
Pair 10	ADI - PSDPP	-2107.800	705.096	222.971	-2612.195	-1603.405	-9.453	9	0.000
Pair 11	ADI - PSDH	-1843.900	359.619	113.722	-2101.156	-1586.644	-16.214	9	0.000
Pair 12	ADI - FDI	-1467.500	694.561	219.639	-1964.359	-970.641	-6.681	9	0.000
Pair 13	ADI - D&SCP	158.400	324.072	102.480	-73.427	390.227	1.546	9	0.078
Pair 14	CDPP - CDH	774.400	535.359	169.295	391.427	1157.373	4.574	9	0.000
Pair 15	CDPP - PSDPP	-1151.800	635.463	200.951	-1606.383	-697.217	-5.732	9	0.000
Pair 16	CDPP - PSDH	-887.900	733.987	232.107	-1412.963	-362.837	-3.825	9	0.002
Pair 17	CDPP - FDI	-511.500	1037.054	327.945	-1253.364	230.364	-1.560	9	0.076
Pair 18	CDPP - D&SCP	1114.400	554.431	175.326	717.784	1511.016	6.356	9	0.000
Pair 19	CDH - PSDPP	-1926.200	523.412	165.517	-2300.626	-1551.774	-11.637	9	0.000
Pair 20	CDH - PSDH	-1662.300	369.151	116.736	-1926.375	-1398.225	-14.240	9	0.000
Pair 21	CDH - FDI	-1285.900	587.911	185.914	-1706.466	-865.334	-6.917	9	0.000
Pair 22	CDH - D&SCP	340.000	331.292	104.764	103.008	576.992	3.245	9	0.005
Pair 23	PSDPP - PSDH	263.900	746.347	236.016	-270.005	797.805	1.118	9	0.146
Pair 24	PSDPP - FDI	640.300	825.548	261.061	49.738	1230.862	2.453	9	0.0185
Pair 25	PSDPP - D&SCP	2266.200	671.666	212.399	1785.719	2746.681	10.670	9	0.000
Pair 26	PSDH - FDI	376.400	725.409	229.395	-142.526	895.326	1.641	9	0.0675
Pair 27	PSDH - D&SCP	2002.300	527.787	166.901	1624.744	2379.856	11.997	9	0.000
Pair 28	FDI - D&SCP	1625.900	761.822	240.909	1080.925	2170.875	6.749	9	0.000

The ‘p’ values obtained from‘t test’ against each pair of information sharing shows statistical significance in almost all cases (accepting alternate hypothesis where p<α) except in following cases (rejecting alternate hypothesis where p>α) : ADI & ‘D&SCP’, CDPP & FDI, PSDPP & PSDH and PSDH & FDI, CDPP&PSDPP, CDPP&PSDH, and PSDPP&FDI.

Result of t test (α=5%) for backorder situation

		Paired Differences					t	df	Sig. (p vale of 1-tailed test) *(Limited to 3 decimal places)*
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	TDL - ADI	7.57500	3.14434	.99433	5.32567	9.82433	7.618	9	0.000
Pair 2	TDL - CDPP	3.65800	3.00754	.95107	1.50653	5.80947	3.846	9	0.002
Pair 3	TDL - CDH	5.40400	2.80567	.88723	3.39694	7.41106	6.091	9	0.000
Pair 4	TDL - PSDPP	3.50900	3.11814	.98604	1.27842	5.73958	3.559	9	0.003
Pair 5	TDL - PSDH	3.59000	1.73590	.54894	2.34821	4.83179	6.540	9	0.000
Pair 6	TDL - FDI	3.62500	1.93577	.61214	2.24023	5.00977	5.922	9	0.000
Pair 7	TDL - D&SCP	8.12100	3.01004	.95186	5.96775	10.27425	8.532	9	0.000
Pair 8	ADI - CDPP	-3.91700	2.23936	.70815	-5.51894	-2.31506	-5.531	9	0.000
Pair 9	ADI - CDH	-2.17100	2.70041	.85394	-4.10275	-.23925	-2.542	9	0.016
Pair 10	ADI - PSDPP	-4.06600	2.42209	.76593	-5.79866	-2.33334	-5.309	9	0.000
Pair 11	ADI - PSDH	-3.98500	3.20320	1.01294	-6.27643	-1.69357	-3.934	9	0.001
Pair 12	ADI - FDI	-3.95000	1.85665	.58712	-5.27816	-2.62184	-6.728	9	0.000
Pair 13	ADI - D&SCP	.54600	1.59186	.50339	-.59274	1.68474	1.085	9	0.153
Pair 14	CDPP - CDH	1.74600	2.91918	.92313	-.34226	3.83426	1.891	9	0.045
Pair 15	CDPP - PSDPP	-.14900	2.39402	.75705	-1.86158	1.56358	-.197	9	0.424
Pair 16	CDPP - PSDH	-.06800	2.62876	.83129	-1.94850	1.81250	-.082	9	0.468
Pair 17	CDPP - FDI	-.03300	2.15675	.68202	-1.57585	1.50985	-.048	9	0.481
Pair 18	CDPP - D&SCP	4.46300	2.23479	.70670	2.86433	6.06167	6.315	9	0.000
Pair 19	CDH - PSDPP	-1.89500	2.26372	.71585	-3.51437	-.27563	-2.647	9	0.013
Pair 20	CDH - PSDH	-1.81400	2.34838	.74262	-3.49393	-.13407	-2.443	9	0.018
Pair 21	CDH - FDI	-1.77900	2.22963	.70507	-3.37398	-.18402	-2.523	9	0.016
Pair 22	CDH - D&SCP	2.71700	2.04583	.64695	1.25350	4.18050	4.200	9	0.001
Pair 23	PSDPP - PSDH	.08100	2.86084	.90468	-1.96552	2.12752	.090	9	0.465
Pair 24	PSDPP - FDI	.11600	1.58332	.50069	-1.01664	1.24864	.232	9	0.411
Pair 25	PSDPP - D&SCP	4.61200	2.40836	.76159	2.88916	6.33484	6.056	9	0.000
Pair 26	PSDH - FDI	.03500	2.25345	.71260	-1.57702	1.64702	.049	9	0.481
Pair 27	PSDH - D&SCP	4.53100	2.32572	.73546	2.86728	6.19472	6.161	9	0.000
Pair 28	FDI - D&SCP	4.49600	1.99454	.63073	3.06919	5.92281	7.128	9	0.000

The ‘p’ values obtained from ‘ t test’ against each pair of information sharing shows statistical significance in almost all case (accepting alternate hypothesis where p<α) except in following cases (rejecting alternate hypothesis where p>α) : ADI & ‘D&SCP’, CDPP & FDI, CDPP &PSDH, CDPP&PSDPP, PSDPP &PSDH, PSDPP & FDI and PSDH & FDI.

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