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Coordinating a three level supply chain with multiple retailers

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Coordinating a three level supply chain with multiple retailers

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Abstract

The objective of this research is to highlight the factors that can optimize the total cost of a centralized supply chain through coordination of order quantities amongst the players in a supply chain. Survey of earlier research reveals that players in a supply chain usually have conflicting interests, such as reducing inventories and increasing profitability. Thus, to make coordination feasible, it is essential to provide proper incentives to individual players. Munson and Rosenblatt (2001) were the first to discuss coordination in a three level supply chain with a single player at each level. On the other hand, Viswanathan and Piplani (2001) are believed to be the first to consider coordination in a two level supply chain with a single vendor and multiple retailers. This research extends upon these works by investigating coordination in a three level supply chain with multiple retailers. This is done by incorporating the model of Viswanathan and Piplani (2001) into that of Munson and Rosenblatt (2001). A new mathematical model is developed, with numerical examples presented and results discussed. When players in a supply chain agree to coordinate, it is possible to have some of the players benefiting more than others in the chain, if not losing. The mathematical model developed in this research work guarantees that the local costs for the players either remain the same as before coordination, or decrease as a result of coordination. Furthermore, this research work assumes that savings generated from coordination should be distributed among the players of the chain. This led to developing a scheme to fairly distribute savings amongst the players of the supply chain. Results indicate that even though players may have conflicting interests in the supply chain, coordination is recommended and should be pursued.

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Nomenclature

A_S= Supplier order cost

A_V= Vendor order cost

A_{Ri} = Retailer *i* order cost

h_S = Supplier holding cost

h_V = Vendor holding cost

h_{Ri} = Retailer *i* holding cost

λ_{Vi} = Vendor lot size multiplier for Retailer *i* for without coordination

λ_{Si} = Supplier lot size multiplier for Retailer *i* for without coordination

Qi = Retailer *i* Economic Order Quantity

Di = Retailer *i* Annual Demand

T_i = Retailer *i* Order cycle length

R_iTC_{wc} = Retailer *i* total cost for without coordination

V_iTC_{wc} = Vendor total cost for Retailer *i* Demand for without coordination

S_iTC_{wc} = Supplier total cost for Retailer *i* Demand for without coordination

$T.Cost_{wc}$ = Total Chain Cost for without coordination

λ_V = Vendor lot size multiplier for with coordination

λs = Supplier lot size multiplier for with coordination

R_iTC_c = Retailer *i* total cost for with coordination

VTC_c = Vendor total cost for with coordination

STC_c= Supplier total cost for with coordination

$T.Cost_c$ = Total Chain cost for with coordination

R_iTC_{cws} = Retailer *i* total cost with coordination without vendor sharing

VTC_{cws} = Vendor total cost for with coordination without vendor sharing

STC_{cws} = Supplier total cost for with coordination without vendor sharing

TC_{cws} = Total chain cost for with coordination without vendor sharing

V_{SAV} = Total Vendor Savings for with coordination without vendor sharing

$V_{SAV\ \%(100)}$ = Total Vendor savings percentage with coordination and without sharing in chain compared to Vendor cost without coordination.

R_iTC_{cs} = Retailer *i* total cost with coordination with sharing in chain

VTC_{wc}= Vendor total cost without coordination in chain

VTC_{cs} = Vendor total cost with coordination with sharing in chain

STC_{wc} = Supplier total cost without coordination in chain

STC_{cs}= Supplier total cost with coordination with sharing in chain

SPB_c = Supplier Pay back of savings after coordination to the Vendor

R_i Dis/u= Retailer *i* discount received from vendor to make retailer cost same as before coordination in the chain

T.C. $_{SAV}$ = Total Chain Savings with coordination with sharing in chain

T.C. $_{SAV\ \%(100)}$= Total Chain cost savings percentage with coordination and sharing in chain compared to Total chain cost without coordination.

Chapter 1

Introduction to Supply Chain Management

The supply chain of a company essentially consists of different facilities, which are geographically dispersed and where raw materials, intermediate products, or finished goods are purchased, processed, stored, or sold, and these facilities are inter-connected through transportation links along which the products flow. It is not usually the case that these facilities are managed by one company; thus, in a supply chain, these facilities can be operated by vendors, customers, third party providers, as divisions of other firms with which the company has business arrangements. The main objective which the company has is to add value to its product as they pass through its supply chain, and then transport these products to different markets in the correct quantities, specifications, time, and at a competitive price.

There are basically two main types of facilities, one is the plants, in which products are manufactured and their physical transformation takes place, and the other is the distribution centers, in which there is no physical transformation, but where products are received, sorted, put away in inventory, picked from inventory, and dispatched. There are also some hybrid facilities, which can be either a plant with distribution capabilities or a distribution center with physical transformation capabilities.

Ballou et al. (2000) explains Supply Chain Management (SCM) as a business term which has replaced the traditional terms used to describe the management of materials and service flows. Lanzenauer and Pilz-Glombik (2002) have a viewpoint that supply chain management primarily handles flow of materials and information and, sometimes, funds within and across the chain. There are some managerial issues with strategic and operational dimensions, which include the design and location of facilities, the specification of supply contracts, the choice of product variety, the management of inventories, and the selection of transportation mode. Supply chain management is a big challenge due to the intricacy of interactions among the components of a system, partial or incomplete information available for decision-making, the presence of multiple decision makers pursuing conflicting objectives and the dynamics of non-stationary conditions. At the same time, the successful handling of these issues has the potential for significant productivity gains.

1.1 Integrated Supply Chain Planning

Lanzenauer and Pilz-Glombik (2002) in their research have suggested that supply chain decisions can be made in a decentralized fashion at each plant/stage or in a centralized way for the whole chain by a planning agency. The particular form of decision-making is not only a function of the prevailing organizational structures in the supply chain, but it is also affected by the location of the information and the authenticity of the data provided to the decision makers.

Supply Chain Management refers to integrated planning, in which it is concerned with the functional integration of purchasing, manufacturing, transportation, and warehousing activities. This is also a spatial integration of these activities across geographically dispersed vendors, facilities, and markets. The enhanced integration of activities across a number of companies sharing components of a supply chain, implies greater sharing of confidential information about costs and capacities, as well as integrative management of the business processes.

Due to advances in IT, the integration in supply chain has been greatly improved, and now managers have much faster access to a much more complete databases than before. The big challenge for them is to take advantage of this capability and create a competitive edge.

1.2 Objectives of Supply Chain Management

One of the considerations in supply chain management is to minimize total supply chain cost to meet the demand. This total cost can include a number of costs such as raw material and other acquisition costs, inbound transportation costs, facility investment costs, direct and indirect manufacturing costs, direct and indirect distribution center costs, setup costs, inventory holding costs, inter facility transportation costs and outbound transportation costs.

The main objective of a firm should be the maximization of net revenues, and not total cost minimization of the supply chain, where Net revenues (profits) = gross revenues – total cost. On the other hand, if demand is fixed and given, then the gross revenues from meeting it are also fixed and given and, therefore, the firm can only maximize its net revenues by minimizing total cost.

1.3. Components of a supply chain

This section lists and briefly discusses the main components of a supply chain, which are production, supply, inventory management, location, transportation, and information.

1.3.1 Production

In a manufacturing concern, the production involves a number of machines producing similar items. The planning horizons can vary from a few days to several weeks, and the demands for the finished products are assumed to be known with certainty in each period of the planning horizon. These demands are fulfilled from finished or semi-finished goods inventory, that is, production can be either make-to-order, make-to-stock of standard products, such as microwaves or tires, or assemble-to-stock of products for which a small amount of customization is allowed, such as in automobiles or printed circuit boards.

The main decisions taken in production planning are, firstly the minimization of avoidable short-term costs, especially machine setup costs and inventory holding costs, secondly, inventory planning for work in process and finished products, and, lastly, the integration of multiple stages of production with varying production lead time.

There has to be a tradeoff while determining the service level. Because of the increasing costs of carrying inventory, the service level provided to customers from a finished goods inventory must be re-evaluated. This means evaluating the value of maintaining service levels versus the savings accrued from reducing the inventory. Most firms understand that 100 percent service is not possible because of the financial constraints. For make-to-stock firms, 100 percent service means massive inventories. For make-to-order firms, immediate delivery translates into large idle capacity. On the other hand, manufacturing planning and control systems are implemented to trade information for inventories and other kinds of slack, including poor delivery performances. By using these systems efficiently, a manufacturer can be close order coupled with customers, that is, demand management can often lead to big improvements in customer service without huge inventories or idle capacity.

1.3.2 Supply

Companies acknowledge the vital nature of purchasing and supplier relations. While managing these functions, the company not only considers the cost of acquisition, but also the quality, responsiveness and flexibility of the supplier. It is these priorities that determine whether the company will maintain an arms length relationship, or develop an alliance with the supplier.

Minner (2003) suggests that the current trends in supplier management and sourcing during the past decade show an increase in global sourcing, a reduction of the supplier base, and long term relationships with suppliers. The main attraction to have a single source is due to the high costs involved in the product design and supplier development, which make it unfeasible to have several suppliers. More attractive terms of contract can be obtained, once the purchasing volume is large e.g., quantity discounts and terms of payment and delivery. The business size influences the bargaining power to negotiate on price, lead times, quality, and flexibility. The main idea of keeping multiple suppliers is to create competition among suppliers to retain the company's business and as a consequence keep supplier costs down and allow the company to impose strict quality and delivery standards on supplier performance. Another reason for having multiple suppliers is that the risk in global sourcing due to exchange rate volatility, supply disruptions due to machine breakdowns, labor strikes or political instability, capacity limitations, lead time variability can be diversified.

1.3.3 Inventory Management

There are a number of reasons why a company needs to hold inventories of raw materials, parts, work-in-process, or finished goods. The main purpose of holding inventories is to protect against the uncertainties of supply and demand, take advantage of economies of scale associated with manufacturing, or acquiring products in large batches, moreover to meet seasonal demands or promotional sales, inventories are required.

In recent years, a lot of emphasis has been given on reducing or eliminating the uncertainties that make inventories necessary. These efforts have gained further importance partly because the metrics which describe the performance of a company's inventory management practices are a strong signal to shareholders regarding the efficiency of the company's operations and hence its profitability. Inventory management problems are mainly concerned with holding costs, shortage costs, and demand distributions for products specified at a detailed stock keeping unit (SKU) level.

1.3.4 Location

Location decisions are very critical both at the national and international level. To setup a new store at the national level, retail analysts screen and select metropolitan and regional markets. At the metropolitan level, not only are the main retail sites critical but also an optimal distribution of those locations is required to serve the marketplace. Distribution facilities must be properly located and sized in order to guarantee that goods can be efficiently linked between manufacturers, stores, and consumers.

In order to minimize the warehousing and transportation costs, the distribution company must design or redesign the network of DCs (Distribution Centers) from which to ship its products to its markets to meet customer demand. In some cases products can move from DCs to markets, and in other cases it could be possible that there are large regional DCs that serve smaller warehouses closer to the markets.

1.3.5 Transportation

The transportation components of a typical supply chain consists of the inbound transportation network which links the company's suppliers to its facilities, the inter facility transportation network which connects its facilities to one another and the outbound transportation network which connects the company's facilities to its customers and markets.

A company can be faced with a choice of transportation modes for shipments along a link; this might include a large truck, small truck, rail, air, or a barge. Even if shipment can be made by one type of truck, the company may have to decide on shipment size, which might be full truckload (FTL) or different sizes of less than truckload (LTL).

To reduce the transportation costs some firms want vendors to build factories in near proximity. Although this might be possible for large companies, where a plant's production is supplied to a single customer, this clearly is not a solution for most vendors. Another solution is for customers to pick up goods from vendors on some prearranged schedule. This cuts down on transportation costs and creates stability and predictability. If the customer picks up the material, some of the uncertainty inherent in vendor deliveries can be eliminated and the factory costs can also be reduced. The customer can, for example, provide containers that can hold the required amounts and will flow as kanbans through the plant. The savings in packaging materials as well as costs of unpacking are welcomed by both parties. All defective items can also be returned easily for replacement, without the accompanying costly return-to-vendor procedures and paperwork.

1.3.6 Information in Supply Chain

In recent years Enterprise Resource Planning systems have provided transactional databases that are comprehensive and easily accessed. These databases make the foundation from which one can develop and apply supply chain modeling systems.

Computers and communications networks must provide managers with timely and complete data about their company's operations, its suppliers, and the markets in which the company's products are being sold.

1.4 Coordination in Supply Chain and Incentives

The main purpose of reviewing current techniques to coordination processes and incentive contracts is to highlight the need for basic and applied research in designing and using these tools to improve supply chain management.

1. *Coordination through the use of common replenishment epochs*: Viswanathan and Piplani (2001) have described this process as one in which the vendor may provide instructions that the replenishment orders for the product are placed only at particular points in time, e.g., the first of every month. The vendor by utilizing this strategy is in fact developing a coordinating mechanism, by which it is able to combine several orders and economize on order processing and delivery costs. If the buyers are used to receiving deliveries at any point in time, then they will be unwilling to accept this kind of an arrangement. Therefore, to get the buyers into some sort of collaboration, the vendor will have to offer them compensation, in the form of a price discount. The main idea of price discount is that it should make up for the buyers for any increase in inventory costs and possibly provide some additional savings. Since the vendor already knows buyers' cost and demand, therefore the buyers' reaction can be foreseen and an optimal decision can be taken.

2. *Quantity and Volume Discounts for Coordination in Supply Chain:* Viswanathan and Wang (2003) have discussed price discounts in detail, and they believe that the main purpose of a price discount is to encourage buyers to buy larger annual volumes and order larger quantities in each replenishment, resulting in lower costs and higher revenue for the vendor. Munson and Rosenblatt (2001) have shown that quantity discount schemes help the vendor achieve economies in order processing and inventory costs, as they encourage the retailer to order in larger sizes. Moreover, they have shown that quantity discounts are a very effective way for improving coordination in a 3 level supply chain. To minimize channel costs the vendor (who is the leader) can request the retailer to order quantities other than their economic order

quantities (EOQ), and then pass on the savings of the supplier to the retailer in order to get the desired cooperation.

This research investigates a three-level coordination, and as such would like to concentrate on the work of Munson and Rosenblatt (2001). In their research they have essentially studied a single vendor with a supplier and a retailer to complete the supply chain. They have explored the idea of reducing the channel costs, by utilizing quantity discounts, in order to achieve better coordination between the channel members. Their model is a decentralized supply chain in which each member makes independent decisions according to their own best interests. The demand is deterministic, and they have shown using the EOQ formulae the possible savings through coordination. The vendor in their model has the lead role and as such his main interest is to increase his/her own savings; however, in order to get maximum collaboration from the supplier and retailer, the vendor distributes the savings in a manner that makes the costs of the supplier and the retailer after coordination indifferent from their costs before coordination. In order to reduce the ordering costs, the vendor entices the retailer to order in larger lot size than its EOQ. This in turn reduces the order processing costs of the supplier, and achieves the maximum cost reduction in the chain. This research shows that coordinating at three levels is more effective than coordinating with the retailer only (27% versus 6%).

Research done by Viswanathan and Piplani (2001) on coordination in supply chains, is also of great importance in the development of this research. They have studied a decentralized supply chain consisting of a single vendor and multiple retailers. The vendor is again the leader in this chain, and he/she tries to combine the orders of the retailers by requesting them to order at one point in time, so that he can cut down on the order processing and delivery costs. However, the retailers are in the habit of ordering when they do not have to hold the product for very long in their inventory; so, to get their cooperation for the common replenishment epoch, the vendor has to offer them price discount. Since the buyers' cost and demand parameters are known, the vendor can anticipate the retailer's reaction. Therefore, he will make an optimal decision while taking that information into consideration. In this research, it has been concluded that the total channel savings can become as high as 35% with coordination.

1.4.1 Integrated Supply Chain Coordination model

In this research the work of Munson and Rosenblatt (2001) has been extended, by applying the concept suggested by Viswanathan and Piplani (2001). The model on which this research is based is a single vendor with single supplier and multiple retailers, unlike Munson and Rosenblatt (2001) who have considered the case of a single retailer. This is a centralized model with deterministic demand, and the objective of the research is to achieve cost savings in the supply chain through coordination. To optimize the total channel costs in this model the vendor will entice the retailers to order lot size quantities other than their EOQ, and the vendor and supplier will order multiples of this lot size. This will increase the cost of the retailers; however, the retailers will be compensated from the savings achieved by the supplier, and will remain indifferent before and after coordination. The concept of Viswanathan and Piplani (2001) will be utilized in this research, and the orders of different retailers will be combined, by requesting the retailers to order at a fixed reorder cycle T, so as to decrease the total order processing costs of the vendor and supplier.

To make the coordination more effective and to gain the interest of all the players, an equitable profit sharing formula has been developed, through which each channel member enjoys the savings after coordination. The savings are distributed in proportion to the costs of the different members before coordination. In this manner complete cooperation and coordination of all channel members with conflicting interests is achieved, and the total costs of the channel are reduced. Some research has been done on coordination and profit sharing in a supply chain. The research of Munson and Rosenblatt (2001) and also that of Viswanathan and Piplani (2001) have already been explained.

The research in this area is not limited to those works discussed above. Other researchers have investigated coordination in supply chain adopting different approaches than those of Munson and Rosenblatt (2001) and Viswanathan and Piplani (2001) some of the relevant works will be briefly discussed. Klastorin et al. (2002) suggested a new mechanism for coordinating orders for the case when vendors in a supply chain outsource their production to an Original Equipment Manufacturer (OEM). Klastorin et al. (2002) developed a model based on the assumption that the vendor has a fixed reorder cycle, T, with the OEM, and the retailers place an integer number of orders within this cycle (i.e. they follow a nested policy). Similar results as those of Munson and Rosenblatt (2001) and Viswanathan and Piplani (2001) were found, when no discount is offered by the vendor, the retailers face higher costs. However, when the vendor offers a discount price, retailers' costs are lower than their non-nested costs. Weng and Zeng (2001) examined the role of quantity discounts in synchronizing production and order cycles for a system consisting of one vendor and two heterogeneous retailers. Their study showed that the benefit of synchronization or coordination decreases with the degree of heterogeneity of the retailers.

Boyaci and Gallego (2002) studied the issue of coordination in a supply chain of one wholesaler and one or more retailers under deterministic price-sensitive demand. Their model provided new ideas on channel coordination and they considered different types of inventory ownership, were they concluded that pricing and inventory replenishment decisions for a coordinated channel should be based on the channel profit function under wholesaler-owned inventory with consignment (WOI-c). Under the (WOI-c), the retailer pays the wholesaler the wholesale price as items are sold. It is furthermore shown that an optimal policy can be implemented cooperatively by an inventory-consignment agreement. This policy is also capable of distributing the gains of channel coordination without requiring side-payments (e.g., franchise fees).

Supply chain management and coordination in a supply chain have been investigated in greater detail by Ballou et al. (2000). In their research on Inter-Organizational Coordination, it is mentioned that researchers are presently modeling the flows and identifying the areas for cost reduction for the whole channel that cannot be achieved by an individual channel member acting alone to optimize its cost structure. If the benefits of coordination reach all concerned parties in a supply chain, then the cooperation is likely to continue along with the benefits. On the other hand, if the cooperation results in one of the parties gaining at the expense of the others, then the coalition will definitely fail. *Therefore in order for the coalition to remain together, the rewards resulting due to cooperation must be redistributed in an equitable manner.* This requires three things. Firstly a new type of measure, which is beyond normal accounting procedures for capturing inter-organizational data and describing them in terms that help benefits analysis. Secondly, an information sharing procedure that provides information about cooperative benefits among the channel members. Finally, there should be an allocation method for redistributing the rewards of cooperation in a manner that is fair and equitable to all parties. In almost all research on inter-organizational coordination, it is presumed that the retailer purchases a product for which the demand is quite predictable and stable. Thus, the retailer functions in an Economic Order Quantity (EOQ) type of an environment i.e., where he/she tries to minimize the setup and holding costs, so that he/she can satisfy the constant demand. The real conflict that arises is because the order quantity that is optimal for the retailer is usually not optimal for the vendor, or for the channel as a whole. A number of researchers, including Heskett and Ballou (1966), Monahan (1984), Weng (1995a), Weng (1995b), Crowther (1964), Dada and Srikanth (1987), Dolan (1987), Lal and Staelin (1984), and Lee and Rosenblatt (1986), have analyzed the effects of coordination in this type of environment. This research is also an extension of this work.

Ballou et al. (2000) suggests that there are two major and distinct informal mechanisms, power and trust, which can be used to develop cooperation in a supply chain. Power is a major concept because its mere presence is thought to affect others. A single member might be so dominant and powerful that the other members may be compelled into acting to achieve the total channel benefits. For example, if the seller had the privilege of being the only supplier, he might pressure the buyer to accept purchasing in a larger quantity. The other method of cooperation is through trust, which is the expectation of a channel member that the word of the other can be depended upon.

Partners committed to a relationship will cooperate with one another because of a desire to make the relationship work. For the trust to work effectively between the partners good communication is required, which is basically the sharing of useful and timely information between the channel members. The other requirement of trust is shared values, which is the extent to which partners have convictions in common about behaviours, goals, and policies.

In their research on supply chain coordination, Moses and Seshadri (2000) describe the issue of finding both a review period and a stocking policy that are jointly favourable to a vendor and a retailer. In their model the retailer faces stationary stochastic demand with independent increments for an item; however, excess customer demand is considered to be lost. To order the item from the vendor's Distribution Center (DC), the retailer uses a periodic review inventory system and a base stock policy. The selling price to customers is fixed, and the vendor uses a make to order system for manufacturing the item. The schedule for production of item is such that it arrives at the DC in advance of the anticipated shipment date. The lead-time from the vendor's DC to the retailer can be random but is definitely less than the review period. The vendor charges a fixed price and extends credit for a fixed duration on each reorder to the retailer. To agree on the base stock level the vendor shares the cost of carrying stocks with the retailer. In order to come to an agreement on base stock level, as well as the length of the review period, the vendor offers credit to the retailer as a function of the length of the review period. The vendor gives a fraction of safety stock at no cost to the retailer on the condition that the vendor will receive the payment once this is sold. In the subsequent periods, the vendor "tops up" this part of the stock based on actual sales. This arrangement therefore increases or decreases credit in a dynamic fashion. As a result of this cost sharing arrangement, whenever there is unsold stock, the vendor has to share the cost of carrying this stock.

Chen et.al. (2001) developed a model that consists of a supplier who distributes a single product to *N* retailers, who in turn serve geographically dispersed retail markets. The demand in each retail market arrives continuously at a constant rate that is a general decreasing function of the retail price in the market. They have devised an optimal strategy for maximizing total system wide profits in a centralized system. Chen et.al. (2001) have shown that the optimum level of channel wide profits can be achieved in a decentralized system. However, this is achieved only if coordination is maintained via periodically charged, fixed fees, and a non-traditional price discount scheme. In this scheme, the discount given to a retailer by the vendor is the sum of three discount components based on the retailer's annual sales volume, order quantity and order frequency.

Corbett and Groote (2000) studied how suppliers use incentive schemes such as quantity discounts to influence buyers ordering pattern, thus reducing the supplier's (and the total supply chain's) costs. They derive the optimal quantity discount policy under asymmetric information and then compare it with a situation in which the supplier has full information. In most of the literature, an important assumption is made that the supplier has full information and can therefore design the quantity discount scheme accordingly; however, this is seldom true in practice. In this research they have discarded the full information assumption, and derive the supplier's optimal quantity discount scheme when the buyer holds private information about her cost structure. The asymmetric information case can also be comprehended as the optimal contract to offer to a group of heterogeneous buyers when the supplier cannot price discriminate. This research describes the optimal pricing policy for N group of buyers of different sizes, holding costs, order costs, and demand rates varying between groups but not within groups. They only vary the buyer's holding costs, but derive the optimal quantity discount policy for an arbitrary continuum of buyer types. To implement a quantity discount scheme as a reduction of unit price, one would have to look into the impact on the holding cost structure. The global efficiency is reduced by information asymmetry but contracting is more efficient than any form of coordination. Secondly, the supplier's expected net costs increase under information asymmetry, and, thirdly, the buyer's net costs decrease when she has private information.

Giannoccaro and Pontrandolfo (2004) proposed a Supply Chain model for coordinating a three-stage SC, which is based on a revenue sharing procedure. The main objective in a SC contract is to (i) increase the total SC profit so as to make it closer to the profit resulting from a centralized control (i.e., channel coordination) and (ii) to share the risks among the SC partners. In particular, a contract model based on a revenue sharing mechanism has been proposed to coordinate a three-stage supply chain. The contract model contains two different contracts: the first is offered by the distributor to the retailer, the second is offered by the vendor to the distributor. It has been shown that an integrated design of the two contracts lets the retailer and the distributor select order quantities that are optimal for the whole supply chain. The success of the SC coordination depends upon the desirability of the contractual scheme by the various players in a supply chain. Therefore, to make all decisions well accepted by the players the adjustment of the contract parameters is essential. Through an application, it has been authenticated that a proper contract design can improve the profitability of the vendor, distributor, and the retailer, as compared to what they would obtain under a market-like setting.

Minner (2003) investigated multiple supply options and discussed strategic aspects of supplier competition and the role of operational flexibility in global sourcing. Dekker et al. (1998) discussed the break quantity rule, which in a multi-echelon system is the maximum issue quantity. If a customer order quantity is larger than the price break quantity, then the customer's request is satisfied directly from the warehouse; otherwise, an associated retailer fulfills the customer's request. The main objective is to find appropriate order-up-to-levels and the break quantity so as to minimize system-operating costs. In the so called no-delay multi-echelon inventory models described by Minner (2003), safety stocks at every stocking point are provided to cover against reasonable demand variability whereas extraordinary large orders are excluded from the analysis by assuming some kind of operating flexibility. This model assumes the presence of two supply alternatives, a regular one for demands not exceeding a known level of variability and an emergency mode to deal with excessive variations. There are some different kinds of models that share some features of multiple supply modes; these are multi-echelon models with lateral trans-shipments. In normal circumstances, a retailer regularly replenishes its material from the warehouse; however, under random demands, the inventory status of the retailers may be out of balance, that is, some retailer may have a lot of inventory whereas others are out of stock. Therefore, instead of just waiting for the next regular warehouse shipment or placing emergency orders at the warehouse, trans-shipments from other, nearby retailers with sufficient inventory might immediately (or after a short lead time) cover the out of stock situation. As a result, retailers face two sources of demand (customers, other retailers) and two sources of supply (warehouse, other retailers).

1.5. Solution Procedure

Coordination amongst players has been explained in some detail in this chapter. The objective of this research is to minimize the cost in a three level supply chain through coordination, by integrating the models of Munson and Rosenblatt (2001) and Viswanathan and Piplani (2001) and developing a new coordination model. To achieve this, a mathematical model will be formulated depicting the coordination in the chain. After that, a profit sharing algorithm will be developed. A program in visual basic will be written and a number of experiments run, in different scenarios, involving varying cost and demand parameters for the players involved, so that the behaviour of the model could be determined. Finally, statistical analysis will be performed on the results, so that the research could be concluded.

Chapter 2

The Integrated Model

In this chapter, the models of Munson and Rosenblatt (2001) and Vishwanathan and Piplani (2001) will be briefly described, and after that the integrated model is presented.

2.1 Assumptions and Methodology in Munson and Rosenblatt Model

In this model, it is assumed that there is a single supplier, a single vendor and a single retailer. The decision making is centralized, and each player acts in its own best interest to minimize its own costs, without any regard to minimize the total chain costs. In this three level channel, all the parameters are deterministic, and the retailer orders the product according to its EOQ. The vendor and the supplier optimize their lot sizing policy according to the lumpy ordering pattern of the retailer and vendor, respectively. The vendor in this model induces the retailer to order a quantity other than its EOQ. A shift from the optimal order policy of the retailer will burden the retailer with additional costs that will be compensated by the vendor. This compensation may take the form of quantity discount. Since the vendor is an influential buyer, it is able to receive a quantity discount from the supplier. The supplier would transfer all (or some) of the savings due to new lot sizes, while not worsening its overall financial condition; moreover, the vendor does not have to compensate the supplier in case the suppliers operating costs increase, since the price to the vendor is not currently linked with the order size. Munson and Rosenblatt (2001) also provided a detailed numerical analysis of their model.

2.2 Assumptions and Methodology in Viswanathan and Piplani Model

In this model the supply chain consists of one vendor with multiple retailers. In order to reduce costs through coordination in the supply chain, the technique of common replenishment epochs (CRE) or periods is utilized by the vendor. In this manner, the vendor is able to combine several replenishment orders from the retailers, and save on order processing and delivery costs. The vendor offers price discounts to the retailers, to accept this policy, and this discount must compensate the retailers for any increase in inventory costs and possibly provide some additional savings. It is assumed that the retailers have constant demand rates, and the retailers' demand parameters are known to the vendor, and therefore, he/she can anticipate the retailers' reactions and will make the best possible decision, while taking that information into consideration. The vendor may follow a lot-for-lot policy i.e., the vendor does not keep any inventory and only orders the required quantity whenever it receives an order from a retailer. The replenishment interval for each retailer should be an integer multiple of the common replenishment period T, so that inventory cost is minimized. It should be noted that the replenishments through the CRE policy is only feasible when order processing costs are larger than a given threshold value, and the situation can be modeled as a Stackelberg game (Basar and Olsder, 1982). This model is also analyzed in detail through numerical examples, in the research paper.

2.3 The Integrated Model

In this section, the models of Munson and Rosenblatt (2001) and Viswanathan and Piplani (2001) are integrated into one model. That is, a three level supply chain with a single supplier, single vendor, and multiple retailers. These retailers may be identical or non-identical, where identical retailers are those having identical order quantities and cycle times. If one or both measures are different amongst retailers, then these retailers are not identical.

Each retailer places an order to the vendor according to its economic order policy, namely the EOQ. In turn, the vendor places orders to its suppliers in multiples of the retailers order lot size. In the case of no coordination, the vendor will manage each retailer separately. Under these conditions, the total cost of the vendor will be excessive as a result of high setup and holding costs. It is in the advantage of the vendor to coordinate the orders received from all retailers to minimize its total cost. However, to have the vendor manage the supply chain more effectively, the vendor should entice the retailers to order in lots that the vendor dictates, and also to order at a particular time, so that the vendor can combine the retailers' orders and save in setup costs. Also, the vendor should entice the supplier to abide with the new order policy.

2.3.1 The case of no coordination

Cost function for retailer i:

$$TC_{Ri}(Q_i) = \frac{A_{Ri}D_i}{Q_i} + h_{Ri}\frac{Q_i}{2} \quad where\ i=1,2,......,n \qquad (1)$$

where A_{Ri}, D_i, h_{Ri} , and Q_i are respectively, the order cost, the demand rate, the holding cost, and the order quantity for retailer i, where i=1, 2, ..., n. The economic order quantity for retailer i is determined by:

$$Q_i^* = \sqrt{2A_{Ri}D_i / h_{Ri}} \tag{2}$$

Cost function for the vendor:

It is assumed that the vendor manages each retailer separately. Then the vendor's total cost is given as:

$$TC_V(\lambda_{Vi} \mid i = 1,2,\ldots,n) = \sum_{i=1}^{n} \left(\frac{A_V D_i}{Q_i \lambda_{Vi}} + \frac{h_V}{2}(\lambda_{Vi} - 1)Q_i \right) \tag{3}$$

where A_V, h_V, and λ_{V_i} are respectively, the vendor's order cost, the vendors holding cost, and the vendor multiplier for retailer's *i* order quantity.

Cost function for the supplier:

Then the Supplier's total cost is given as:

$$TC_S(\lambda_{Si} \mid i = 1,2,\ldots,n) = \sum_{i=1}^{n} \left(\frac{A_S D_i}{Q_i \lambda_{Vi} \lambda_{Si}} + \frac{h_S}{2} \lambda_{Vi} (\lambda_{Si} - 1)Q_i \right) \tag{4}$$

where A_S, h_S, and λ_{S_i} are respectively, the supplier's order cost, the vendors holding cost, and the supplier multiplier for the vendor's order resulting from retailer's *i* order quantity.

The total cost of the supply chain is determined from (1), (3) and (4) as:

$$\begin{aligned} TC_{Chain}(Q_i, \lambda_{Vi}, \lambda_{Si} \mid i = 1,2,\ldots,n) = & \sum_{i=1}^{n} \left(\frac{A_{Ri} D_i}{Q_i} + \frac{h_{Ri}}{2} Q_i \right) + \\ & \sum_{i=1}^{n} \left(\frac{A_V D_i}{Q_i \lambda_{Vi}} + \frac{h_V}{2}(\lambda_{Vi} - 1)Q_i \right) + \\ & \sum_{i=1}^{n} \left(\frac{A_S D_i}{Q_i \lambda_{Vi} \lambda_{Si}} + \frac{h_S}{2} \lambda_{Vi} (\lambda_{Si} - 1)Q_i \right) \end{aligned} \tag{5}$$

In Eq (5), the total channel cost is shown when there is no coordination in the chain. It can be observed that in case of lot- to-lot ordering the lot size multiplier equals 1, and therefore the hólding cost becomes zero, for the vendor and supplier.

In Fig (1) the vendor inventory level in solid line, can be observed when it is placing small lot size orders to its supplier at small order cycle length, and the dashed line shows the inventory level with coordination when the orders from retailers have been combined, and hence the order cycle length of the vendor increases, which results in cost savings for the vendor, as well as for the supplier.

2.3.2 The case of with coordination (no sharing of savings)

In case of non-identical retailers i.e., $T_i \neq T_j$, for retailers *i* and *j*, the retailers order quantities could be adjusted, such that their cycle lengths become identical that is $T = Q_i / D_i$ where *i* indicates a particular retailer. Then, (1) could be rewritten as:

$$TC_{Ri}(T) = \frac{A_{Ri}}{T} + \frac{h_{Ri} D_i T}{2} \tag{6}$$

equation (3) as:

$$TC_V(\lambda_V, T) = \frac{A_V}{T\lambda_V} + \frac{h_V}{2}(\lambda_V - 1)\sum_{i=1}^{n} D_i \tag{7}$$

and equation (4) as:

$$TC_S(\lambda_V, \lambda_S, T) = \frac{A_S}{T\lambda_V \lambda_S} + \frac{h_S}{2}\lambda_V(\lambda_S - 1)\sum_{i=1}^{n} D_i \tag{8}$$

The supply chain total cost is formulated as a non-linear mathematical programming model as:

$$\text{Minimize } TC_{Chain}(\lambda_V, \lambda_S, T) = \sum_{i=1}^{n}\left(\frac{A_{Ri}D_i}{T} + \frac{h_{Ri}D_i}{2}T\right) + \frac{A_V}{T\lambda_V} + \frac{h_V}{2}(\lambda_V - 1)\sum_{i=1}^{n} D_i + \frac{A_S}{T\lambda_V\lambda_S} + \frac{h_S}{2}\lambda_V(\lambda_S - 1)\sum_{i=1}^{n} D_i \quad (9a)$$

Subject to:

$$T \geq 1/\max(D_i \mid i = 1,2,\ldots,n) \quad (9b)$$

$\lambda_V, \lambda_S \geq 1$, where lambdas are integer values (9c)

Then, for example, the discount per unit that the vendor would offer each retailer that would make the retailer indifferent between placing orders of size Q or its EOQ, Munson and Rosenblatt (2001), is computed as follows:

$$\varnothing_i(T^*) = \left[\frac{A_{Ri}}{T^*} + \frac{h_{Ri}D_iT^*}{2} - \frac{A_V D_i}{Q_i^* \lambda_{Vi}^*} - \frac{h_V}{2}(\lambda_{Vi}^* - 1)Q_i^*\right]D_i^{-1} \quad (10)$$

In Fig (1) it can be seen that the Supplier is replenishing the vendor's inventory and the vendor is replenishing the retailer's inventory, moreover the supplier has to maintain the highest inventory level in the Supply Chain

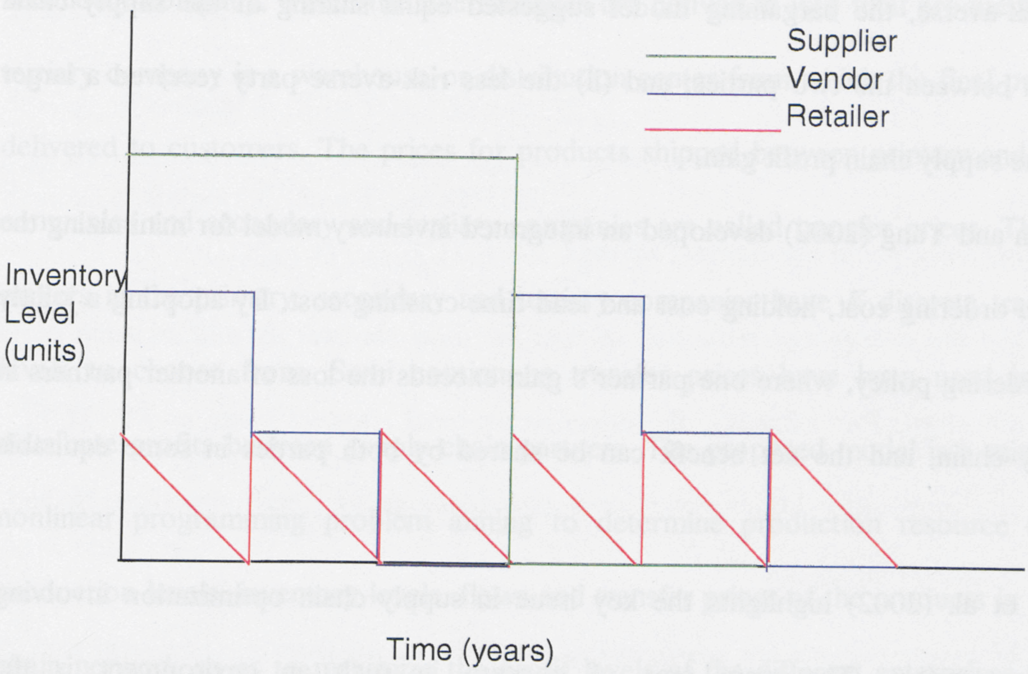

Fig (1). Inventory level of the Supply Chain players versus time

2.4. Equitable Sharing of Savings

There has been some considerable research done on Supply Chain profit sharing during coordination. Li et al., (2002) demonstrated that (i) the supply chain profits at cooperation were higher than for a two-stage non-cooperation; (ii) the supply chain profits were maximized for a single retail price but with a set of other decision variables; (iii) there was a set of cooperative payment schemes on which both the franchiser and the franchisee achieved higher profits than at non-cooperation. With respect to those acceptable payment schemes, the main issue was selection of the best scheme for both partners as well as how to divide the supply chain profit gains. These issues were addressed, by utilizing the Nash (1950) bargaining model. It was shown that, under some special utility forms: (i) if the franchiser and the franchisee were risk-neutral or were equally risk-averse, the bargaining model suggested equal sharing of the supply chain profit gain between the two parties; and (ii) the less risk-averse party received a larger share of the supply chain profit gain.

Pan and Yang (2002) developed an integrated inventory model for minimizing the sum of the ordering cost, holding cost and lead time crashing cost. By adopting a jointly optimal ordering policy, where one partner's gain exceeds the loss of another partners in the supply chain, and the net benefit can be shared by both parties in some equitable fashion.

Gjerdrum et al. (2002) highlights the key issue in supply chain optimization involving multiple enterprises. The main area of concern in such an environment is the determination of policies that optimize the performance of the total supply chain, while at the same time ensure adequate rewards for each channel member. They have considered fair profit sharing in a two-enterprise supply chain, and have presented a spatial branch-and-bound algorithm, which utilizes the game theoretical bargaining concepts developed by Nash (1950). The results obtained have been compared with those obtained by using a simple single level optimization approach which focuses on the total profit generation of the entire supply chain. Semi-continuous transfer prices have been used in order to give out profits to the two supply chain partners. The computational results have shown that the proposed method produces profits very close to the supply chain optima, but are much more equitably distributed.

In an earlier paper, Gjerdrum et al. (2001) considers a supply chain in which there are N different enterprises. There are three different types of nodes in the supply chain. A primary company produces intermediate products, which are then delivered to a secondary company, where the intermediates are converted into final products. Finally, a tertiary company is a warehouse or distribution center from which the final products are delivered to customers. The prices for products shipped between primary and secondary companies and secondary and tertiary companies are called transfer prices. The decision makers in the primary, secondary and tertiary companies have K discrete transfer price levels to choose from. Semi continuous transfer prices have been used in order to distribute profits between supply chain partners. The proposed model is a mixed integer nonlinear programming problem aiming to determine production resource utilization, production levels, inventory levels, flows and transfer prices of the products in the supply chain network so as to maximize the profit levels of the different enterprises fairly. The numerical results show that the proposed method produces equitably distributed profits.

After reviewing different coordination models and profit sharing schemes, the proposed model has been developed in channel coordination, cost reduction and equitable sharing of profits. There are two different profit sharing schemes, one is in which the vendor gains the maximum, and this option can be utilized for highly influential vendors like General Motors, IBM etc., while the other option is more practical and in this the profit sharing is done equitably amongst the chain members. The main idea behind the equitable sharing option is that all the players are motivated to cooperate and coordinate, since each member is better off with coordination than without coordination in the supply chain.

To make the coordination more effective a profit sharing formula has been developed, through which each channel member enjoys the savings through coordination. The same basic procedure is used for non-identical as well as identical retailers. The savings are distributed in proportion to the costs of the different members before coordination as follows:

Step 1: Find the total channel costs, with, TC^{WC}_{Chain}, *and with no coordination* TC^{NC}_{Chain}, *with the difference being the channel savings,* $SV = TC^{NC}_{Chain} - TC^{WC}_{Chain}$.

Step 2: Find the percentage reduction in cost for total channel as well as each player after coordination. For example, % reduction in total channel costs = SV / TC^{NC}_{Chain}. *Some players may suffer losses others may experience gains.* Determine these % and $ gains and losses for all players.

Step 3: The losing players are compensated for their losses from the player(s) with the most savings. Re-compute all the costs for all players after the compensation. The result would be that the players who suffered losses due to coordination would have their costs reset to their original values before coordination, with SV clustered with the other players.

Step 4: For a fair share of savings, it is assumed that each player in the channel would have his/her cost reduced by SV / TC^{NC}_{Chain}. *The costs computed from step 3 are readjusted to represent this % reduction. To make sharing of savings equitable between all the players the % reduction in cost of each player should be equal to that of % reduction in channel cost i.e., X%=Y%=Z%=W1%=W2%=W3%; however, if X%%≠Y%≠Z%≠W1%≠W2% ≠W3% then in order to make the sharing equitable among all the players, the savings (SV) are redistributed in proportion to the players cost w/o coordination to the total channel cost w/o coordination.*

Savings of Supplier $S_s = TC_s * SV / TC^{NC}_{Chain}$

Savings of Vendor $S_v = TC_v * SV / TC^{NC}_{Chain}$

Savings of Retailer 1 $S_{r1} = TC_{r1} * SV / TC^{NC}_{Chain}$

Savings of Retailer 2 $S_{r2} = TC_{r2} * SV / TC^{NC}_{Chain}$

Savings of Retailer 3 $S_{r3} = TC_{r3} * SV / TC^{NC}_{Chain}$

Step 5: Finally determine the total cost of each player after receiving equitable share of the channel savings.

The Cost of Supplier after sharing $TC_{ss} = TC_s - S_s$

The Cost to Vendor after sharing $TC_{vs} = TC_v - S_v$

The cost to Retailer1 after sharing $TC_{r1s} = TC_{r1} - S_{r1}$

The cost to Retailer2 after sharing $TC_{r2s} = TC_{r2} - S_{r2}$

The cost to Retailer3 after sharing $TC_{r3s} = TC_{r3} - S_{r3}$

Chapter 3

Data Analysis

After conducting 252 experimental runs of the model in different scenarios, it has been observed that the total cost of the chain reduces after coordination between the different players. The experiments have been done for both identical retailers, i.e., those retailers that have the same order cycle $T = Q_i/D_i$ where i indicates a particular retailer, and for non-identical retailers, i.e., $T_i \neq T_j$ for retailers i and j. In Appendix-I, the results of twelve experimental cases have been shown, with different behavioral patterns of the setup/order costs of the players, so that the affect on channel savings can be observed. Case 1, non-identical retailers are considered with the supplier setup/order cost being highest in the chain, with that of the retailers being the lowest, while case 2 has similar setup/order costs but it has identical retailers. Similarly, the channel savings are observed in different scenarios (case 3-12) by increasing/decreasing the setup/order costs of players upstream/downstream in the Supply Chain. In these cases five patterns can be observed for the setup/order costs of the players in the Supply Chain. Cases 1, 2, 9 and 12 follow the pattern where supplier setup/order cost is highest and retailer's setup/order cost the lowest in the supply chain. The supply chain savings vary from 44.5% to 71.5%, with the highest savings realized in case 9 where the holding costs of the supplier and the vendor are higher than in other similar cases. The second pattern consists of cases 3 and 4, where retailers setup/order cost is highest and supplier setup/order cost the lowest in the chain. It can be observed that with this type of setup in the Supply Chain the channel savings are the lowest i.e., 15.2%. In the third pattern which consists of cases 5, 6 and 11 the vendor has the highest setup/order cost and the retailers have the lowest setup/order cost. Here again it can be observed that the highest savings of 71.5% are achieved with comparatively higher holding costs of vendor and supplier than in the other similar cases. Case 10 comes in the fourth type of pattern i.e., the vendor has the highest setup/order cost and supplier has the lowest setup/order cost in the supply chain. The savings of the supply chain are not very high and are only 33.9%. The fifth pattern consists of cases 7 and 8, in which the retailer's have the highest setup/order cost and vendor the lowest setup/order cost. The channel savings are very low for this type of pattern and are only 15.2%.

In order to get a better understanding of these experimental cases, the results of case 1 will be discussed. This case assumes non-identical retailers in a three level supply chain with the supplier having the largest order cost is in the channel. It can be observed in Table 1 (a), Appendix-I, in which there is no coordination in the chain, the lot size multipliers (λ_{v1}, λ_{v2}, λ_{v3}) of the vendor, as well as the suppliers (λ_{S1}, λ_{S2}, λ_{S3}) for each one of the three retailers order. The order lot size for the three retailers is Q_{1wc}, Q_{2wc}, Q_{3wc} and it can be observed that for retailer 1 the vendor has the lot size multiplier equal to 2. Furthermore retailer 1 order lot size is 1,061 units; therefore, the vendors order lot size for the retailer1 becomes 2,122 units, which is placed on the supplier. Since the supplier's lot size multiplier for vendors order for retailer1 is one, therefore the order lot size of the supplier remains as 2,122 units. In Table 1 (b), Appendix-I, the channel cost of the three retailers ($R1TC_{wc}$, $R2TC_{wc}$, $R3TC_{wc}$), as well as the cost of the vendor ($V1TC_{wc}$, $V2TC_{wc}$, $V3TC_{wc}$) and supplier ($S1TC_{wc}$, $S2TC_{wc}$, $S3TC_{wc}$) for each retailer order, is shown when there is no coordination in the chain. In Table 1 (c), (d) and (e) Appendix-I, the results after the coordination in the chain, can be observed. In Table 1 (c) Appendix-I it can be seen that the model optimizes the retailers order lot sizes ($Q1_c$, $Q2_c$, $Q3_c$) that minimize the total channel cost. With coordination, the reorder cycle T in the model, which is also shown in Table 1 (c), is assumed to be the same for all retailers. Consequently, the vendor and the vendor's supplier will have a single lot size multiplier, which are λ_v and λ_S respectively, rather than different multipliers to accommodate all retailers. This significantly reduces the supply chain total cost. These results are summarized in Table 1 (d), which shows that with coordination (with no sharing of savings assumed) the total supply chain cost, T-Cost, is reduced by about 55% (from 180,368 to 81,056). The costs for the three retailers, from Table 1(c), after coordination are, respectively, 12,501 for the first retailer, $R1TC_c = 12{,}501$, 18,474 for the second retailer, $R2TC_c = 18474$, and 16,871 for the third retailer, $R3TC_c = 16{,}871$. Comparing these results with those without coordination, Table 1 (a), one may notice that coordination is not profitable for any of the retailers. The retailers will incur losses of 4,016 (loss of retailer no. 1=12,501 – 8,485), 6,474 (loss of retailer no. 2 = 18,474 –12,000), and 3,455 (loss of retailer no. 3 = 16,871–13,416) respectively. To have the retailers accept coordination, their costs after coordination should be less than or equal to theirs before coordination. Thus, the retailers must be compensated for their losses. It could be easily noticed that both the vendor and the supplier benefited from the coordination case. With no coordination, the vendor and subsequently the supplier have to treat the order of each retailer independently. That is, they would incur high order and holding costs. With coordination it is possible for the vendor and the supplier to consolidate their orders and thus significantly reduce their costs. For example, the vendor's cost reduces from 65,837 (sum of the cost of accommodating the three retailers independently, i.e., 22,095 + 22,500 + 21,242 = 65,837) to 11,070 in Table 1 (b). Consequently, the supplier's cost reduces from 80,630 to 22,140. The vendor will compensate the retailers for their losses. This will increase the vendor's cost to 25,015 (11,070 + 4,016 + 6,474 + 3,455 = 25,015). Should the case be that the savings from coordination are clustered at the supplier's end, the supplier has to compensate the players at the lower end of the supply chain. That is, the supplier compensates the vendor for its losses and that of the retailers, where the vendor in its turn compensates the retailers for their losses.

To have long term partnership, it will be assumed that every player will have its cost reduced by the same percentage at that of the chain. The total supply chain cost with coordination, Tables 1(b) & (c), reduced from 180,368 to 81,056, representing a reduction of about 55% ((180368-81056) x100/180368= 55.1%). This means that the retailers' costs will be reduced to 3,813, 5,393, and 6,029 from 8,485, 12,000, and 13,416 respectively, the vendor's cost to 29,587 from 65,837, and the supplier to 36,235 from 80,630.

The main reason for the savings in cost is that with coordination the retailers tend to order in larger quantities at equal intervals of fixed length *T*, *T* =0.018 years or 6.57 days in Table1(c), which reduces the number of orders placed by the vendor and supplier. This is a consequence of the orders consolidation policies that both the supplier and vendor adopt to significantly reduce their holding and order costs. Results also indicate that there is no significant difference in the channel savings of identical and non-identical cases with similar parameters. Results in Table 6(e) show that for the case where the retailers are identical the channel savings are 51.10 %, which is less than that for the case where the retailers are non-identical, Table 5(e) with channel savings 55.91%, for similar parameters. The reason for this behavior is that when the retailers are identical there is less potential for savings, since the order pattern of the retailers is synchronized, and the vendor as a result incurs less ordering and holding costs. The model presènted in this study has also been tested for different patterns of set-up/ordering costs along the chain, as mentioned previously. For the case when the vendor's setup cost is the lowest in the channel, the vendor's savings can go up to 500% of his/her initial cost before coordination; see Tables 7 (d) and 8 (d). This study assumes that there is no supply chain leader which allows for equitable sharing of savings amongst all the chain members. This allows the equal sharing of profits. Table 1 (d) shows that the savings are clustered with the vendor who shares the savings (99317) with the retailers and the supplier. The vendor shares some of the savings with the retailers and the supplier to reduce their costs by 55.06% from their original values. The retailers' costs will reduce respectively from 8485, 12000, 13416, in Tables 1(b) and (d) to 3813, 5393, 6029 in Table 1 (e) with the supplier's cost reducing from 80630, in Tables 1 (b) and (d), to 36235, in Table 1(e), as a result of equitable profit sharing in the chain. This will increase the vendor's cost from –33475 in Table 1(d) to 29587 in Table 1(e), or alternatively, reducing the vendor's cost from 65837 to 29587. The examples provided in Tables (1) and (2) were replicated for different values of the input parameters with results provided in the Appendix I (Tables (3)-(12)).

3.1. Regression Analysis

To draw further conclusions, a regression analysis was done on the 252 experimental results as shown in Table (A), Appendix-II. The model that has been used to test the relationship between 13 independent variables and one dependent variable is a multiple linear regression model

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots\ldots\ldots\ldots\ldots + \beta_{13} x_{13} + \varepsilon$$

This model assumes that a linear relationship exists between each independent variable ($x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}$) and the dependent variable y. The variables refer to the following:

y	Savings in the chain due to coordination
x_1	Annual demand of retailer 1
x_2	Annual demand of retailer 2
x_3	Annual demand of retailer 3
x_4	Setup cost of Supplier
x_5	Setup cost of Vendor
x_6	Setup cost of Retailer 1
x_7	Setup cost of Retailer 2
x_8	Setup cost of Retailer 3
x_9	Holding cost of Supplier
x_{10}	Holding cost of Vendor
x_{11}	Holding cost of Retailer 1
x_{12}	Holding cost of Retailer 2
x_{13}	Holding cost of Retailer 3

where $\beta_0, \beta_1, \ldots\ldots \beta_{13}$ are the unknown regression parameters and ε is a random error. The null hypothesis for this model is H_0: $\beta_0 = \beta_1 = \beta_2 \ldots\ldots = \beta_{13} = 0$, and the alternative hypothesis is H_a: $\beta_i \neq 0$; where i=1....,13. The output that was obtained after running the regression analysis computer program, based on the least squares method are shown in Table (B), Appendix-II. An analysis of the most important quantities appearing in the computer output follows.

R^2 (coefficient of determination): The proportion of variation in channel savings explained by the model is $R^2 = 0.9297$. Thus approximately only 8% of the variation in channel savings is left unexplained, which demonstrates a strong relationship between the independent variables and the channel savings.

F value: The F value to be used to determine whether these results with such a high value of R^2 occurred by chance. The term " α " is used for the probability of erroneously concluding that there is a relationship. There is a relationship among the variables if the F-observed statistic is greater than the F-critical value. To read the table, a single-tailed test is assumed, while using an α value of 0.05, and for the degrees of freedom, using v1 = k = 13 and v2 = n – (k + 1) = 252 – (13 + 1) = 238, where k is the number of variables in the regression analysis and n is the number of data points. The F-critical value is 1.72 from the table and the F-observed value is 242.12 from the computer output, which is substantially greater than the F-critical value of 1.72. Therefore, the regression equation is useful in predicting the savings of the channel.

t value: Another hypothesis test is the *t* test which will determine whether each slope coefficient is useful in estimating the savings of the channel. The students t-distribution table was consulted, and found that t-critical, two tailed test, with 238 degrees of freedom and $\alpha/2$ = 0.025 (95% confidence level) is 1.9. Now five independent variables had a *t value* greater than 1.9, these are x_4, x_5, x_6, x_7, x_8, i.e., setup cost of supplier, vendor and the three retailers. It is known that every statistical test has an associated *p value*. The *p value* is defined as the probability, calculated under the null hypothesis, of obtaining a value of the statistic that is as extreme as the one observed for the data (in a given direction). Intuitively, you can think of the *p value* as the strength of the evidence against the null hypothesis. The weaker the *p value*, the lower the probability of obtaining by chance a result that is as extreme as the observed result, and therefore the more significant the result. The traditional way to use a type I error α is to accept the alternative hypothesis if the *p value* is less than or equal to α. Since the *p value* for x_4 is 2.69 $\times 10^{-11}$ which is much less than $\alpha = 0.05$, therefore it has statistical significance and x_4 is a important variable in estimating channel savings y, and therefore reject the null hypothesis H_0: $\beta_4=0$ at a level of significance α = 2.69 $\times 10^{-11}$. A similar conclusion can be made of statistical significance for x_5, x_6, x_7, and x_8. Now for all the rest of the independent variables the absolute *t value* is less than 1.9, and *p value* is higher than α=0.05; therefore, removing the corresponding variables would have little effect on the quality of the fit of the model. The regression analysis output shows that the players' setup costs have a correlation with the channel savings y. As explained earlier, with the higher supplier setup cost, the potential to save in the channel becomes greater with coordination, which results in greater channel savings due to coordination.

These results conform to the findings of Munson and Rosenblatt (2001) as well as Vishwanathan and Piplani (2001), suggesting that effective coordination in a supply chain can result in valuable savings for all the concerned members of the chain.

Incentives in the form of quantity discounts can be adopted to achieve cooperation amongst the players in the chain. These results also show that the potential savings increase with the number of retailers, as shown in Table 12 (e) for exactly the same parameters as in the example in Munson and Rosenblatt (2001). Also the channel savings increase from 27.22% Munson and Rosenblatt (2001) model with one retailer, to 44.56% for this model with three identical retailers; however, it has to be kept in view that in this model there is also a significant contribution made because of matching of order frequency of the retailers.

Chapter 4

Summary, Conclusions and future research

This research project investigates a three-level supply chain with multiple retailers, who may be non-identical. This was done by integrating the model of Viswanathan and Piplani (2001) and that of Munson and Rosenblatt (2001). The resultant model combines the inherent characteristics of both models. The suggested model achieves coordination amongst the members in a supply chain, to reduce the total cost of the chain by searching for a common and optimal cycle time for all non-identical retailers. This facilitates the consolidation of orders by the vendor and subsequently its supplier. Consolidation of orders in a supply chain results in reducing the order processing costs of the chain members, while fulfilling the annual demand. However, this comes at a cost for the player in the supply chain with the maximum savings. To entice retailers to order according to a predetermined schedule that is moving away from their economic order quantities, the benefiting (dominant) player i.e., the vendor, should first compensate the losing players i.e., retailers, by offering quantity discounts. This will make the retailers' cost indifferent before and after coordination. Further, in this research project it is assumed that the remaining supply chain savings are shared according to an agreed upon scenario.

The results show that, after conducting 252 experiments in different scenarios, which involved varying cost and demand parameters of the players in the supply chain, in order to evaluate the affect of coordination on the total cost of a 3 level chain for identical and non-identical retailers, under certain circumstances the channel savings can improve to a great extent. The idea behind this model is to optimize the number of setups required by different players to meet the total annual demand. In the case of without coordination of retailers, that is, each order of different retailers is received separately by the vendor and the vendor does not dictate the lot size, the channel savings are not optimized. On the other hand, when the vendor influences them to coordinate, they combine their individual orders into one big order for the vendor. This reduces the number of orders required by the vendor, as well as the supplier, to meet the demand, and thus reduces the total chain costs. The savings achieved by the supplier and vendor are passed on to the retailers, so that their costs remain the same with and without coordination. In the scenario without sharing amongst the chain members, the member who gains in this exercise is the influential vendor, whose savings can go up to more than 500% of its original cost before coordination, since the vendor not only reduces its own operating costs but also receives all the extra savings from the supplier, which it got after coordination in the chain. These substantial savings for the vendor take place only when the setup cost for the vendor is the minimum in the chain and the setup cost of the retailers is the maximum. This results in the vendor order lot size to increase tremendously after coordination, and therefore the annual demand of the retailers is met with fewer setups by the vendor and the supplier, which decreases their operating costs as compared to those before coordination. Similarly, in the savings sharing scenario the maximum total channel savings are around 72% of the original total cost before coordination takes place. The maximum total channel savings take place in the event when the combined retailers' setup costs are minimum in the chain, and the suppliers setup cost the maximum. It has been verified by a multiple regression exercise that the channel savings are influenced most by the supplier cost.

It can be concluded, after completing this research, that supply chain coordination can bring gains for the players involved. However, to achieve the optimal level of coordination there are different trade credit options that could be adopted, of which quantity discounts was adopted in the project. Other options such as permissible delay in payments could also be considered in a future extension of the work presented herein. There is no best way; it depends upon the circumstances and environment in the supply chain, which method of coordination can bring optimum results and reduce the total cost of the supply chain.

It has also been observed that this model works well for both identical and non-identical retailers, and in both cases the results are very encouraging, as far as vendor savings and total channel savings are concerned. In the case of identical retailers, the ordering cycle T is already the same for each retailer, which naturally results in lower channel costs. This saving improves with larger lot size when the players coordinate, and as a result of this fewer setups are required by the vendor to meet the demand. However, for non-identical retailers, it is observed that the channel savings is slightly more than in the identical case, since before coordination the ordering cycle is different for the retailers, and only after coordination the ordering cycles are matched, and as a consequence the order processing costs decrease, which results in greater channel savings.

An immediate extension of the work presented here in to include multi-supplier, multi-vendor multi-retailer chain, with multiple products, where the model can also give credit for timely deliveries and quality of products. This suggested extension is a more realistic representation of real-life situations.

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APPENDIX-I

Notations:

S_S = Supplier setup cost

S_V = Vendor setup cost

S_{R1} = Retailer 1 setup cost

S_{R2} = Retailer 2 setup cost

S_{R3} = Retailer 3 setup cost

H_S = Supplier holding cost

H_V = Vendor holding cost

H_{R1} = Retailer 1 holding cost

H_{R2} = Retailer 2 holding cost

H_{R3} = Retailer 3 holding cost

λ_{v1} = Vendor lot size multiplier for Retailer 1 for without coordination

λ_{v2} = Vendor lot size multiplier for Retailer 2 for without coordination

λ_{v3} = Vendor lot size multiplier for Retailer 3 for without coordination

λ_{S1} = Supplier lot size multiplier for Retailer 1 for without coordination

λ_{S2} = Supplier lot size multiplier for Retailer 2 for without coordination

λ_{S3} = Supplier lot size multiplier for Retailer 3 for without coordination

$Q1_{wc}$ = Retailer 1 Order lot size for without coordination

$Q2_{wc}$ = Retailer 2 Order lot size for without coordination

$Q3_{wc}$ = Retailer 3 Order lot size for without coordination

D1 = Retailer 1 Annual Demand

D2 = Retailer 2 Annual Demand

$D3$ = Retailer 3 Annual Demand

$R1TC_{wc}$ = Retailer 1 total cost for without coordination

$R2TC_{wc}$ = Retailer 2 total cost for without coordination

$R3TC_{wc}$ = Retailer 3 total cost for without coordination

$V1TC_{wc}$ = Vendor total cost for Retailer 1 Demand for without coordination

$V2TC_{wc}$ = Vendor total cost for Retailer 2 Demand for without coordination

$V3TC_{wc}$ = Vendor total cost for Retailer 3 Demand for without coordination

$S1TC_{wc}$ = Supplier total cost for Retailer 1 Demand for without coordination

$S2TC_{wc}$ = Supplier total cost for Retailer 2 Demand for without coordination

$S3TC_{wc}$ = Supplier total cost for Retailer 3 Demand for without coordination

$T.Cost_{wc}$ = Total Chain Cost for without coordination

λ_V = Vendor lot size multiplier for with coordination

λ_S = Supplier lot size multiplier for with coordination

$Q1_c$ = Retailer 1 Order lot size for with coordination

$Q2_c$ = Retailer 2 Order lot size for with coordination

$Q3_c$ = Retailer 3 Order lot size for with coordination

T = Time period for new order placement for with coordination

$R1TC_c$ = Retailer 1 total cost for with coordination

$R2TC_c$ = Retailer 2 total cost for with coordination

$R3TC_c$ = Retailer 3 total cost for with coordination

VTC_c = Vendor total cost for with coordination

STC_c= Supplier total cost for with coordination

$T.Cost_c$ = Total Chain cost for with coordination

$R1TC_{cws}$ = Retailer 1 total cost with coordination without vendor sharing

$R2TC_{cws}$ = Retailer 2 total cost with coordination without vendor sharing

$R3TC_{cws}$ = Retailer 3 total cost with coordination without vendor sharing

VTC_{cws} = Vendor total cost for with coordination without vendor sharing

STC_{cws} = Supplier total cost for with coordination without vendor sharing

TC_{cws} = Total chain cost for with coordination without vendor sharing

V_{SAV} = Total Vendor Savings for with coordination without vendor sharing

$V_{SAV\ \%(100)}$ = Total Vendor savings percentage with coordination and without sharing in chain compared to Vendor cost without coordination.

$R1TC_{cs}$ = Retailer 1 total cost with coordination with sharing in chain

$R2TC_{cs}$= Retailer 2 total cost with coordination with sharing in chain

$R3TC_{cs}$= Retailer 3 total cost with coordination with sharing in chain

VTC_{wc}= Vendor total cost without coordination in chain

VTC_{cs} = Vendor total cost with coordination with sharing in chain

STC_{wc} = Supplier total cost without coordination in chain

STC_{cs}= Supplier total cost with coordination with sharing in chain

SPB_c = Supplier Pay back of savings after coordination to the Vendor

R1 Dis/u= Retailer 1 discount received from vendor to make retailer cost same as before coordination in the chain

R2 Dis/u= Retailer 2 discount received from vendor to make retailer cost same as before coordination in the chain

R3 Dis/u= Retailer 3 discount received from vendor to make retailer cost same as before coordination in the chain

$T.C._{SAV}$ = Total Chain Savings with coordination with sharing in chain

$T.C._{SAV\ \%(100)}$= Total Chain cost savings percentage with coordination and sharing in chain compared to Total chain cost without coordination.

Case 1. Optimal order quantities, vendor savings in a non -identical three level supply chain (Supplier-Vendor-3 Retailers) with coordination for the case of maximum setup costs for the supplier and minimum for the retailers in the chain (S_S=400, S_V=200, S_{R1}=30, S_{R2}=40, S_{R3}=60) and holding costs (H_S=20, H_V=15, H_{R1}=8, H_{R2}=12, H_{R3}=10) with constant demand, D1=D2=D3=150,000.

Table 1 (a) Without coordination (lot size multiplier for vendor and supplier, lot size for retailers)

λ_{v1}	λ_{v2}	λ_{v3}	λs_1	λs_2	λs_3	$Q1_{wc}$	$Q2_{wc}$	$Q3_{wc}$
2	2	2	1	1	1	1061	1000	1342

Table 1 (b) Without Coordination (Retailers cost, vendor cost, supplier cost and total chain cost)

$R1TC_{wc}$	$R2TC_{wc}$	$R3TC_{wc}$	$V1TC_{wc}$	$V2TC_{wc}$	$V3TC_{wc}$	VTC_{wc}	$S1TC_{wc}$	$S2TC_{wc}$	$S3TC_{wc}$	STC_{wc}	$T.Cost_{wc}$
8485	12000	13416	22095	22500	21242	65837	28275	30000	22355	80630	180368

Table1 (c) With coordination (retailers cost, vendor cost, supplier cost, time period, lot size multiplier for vendor and supplier, lot size for retailers and total cost).

$R1TC_c$	$R2TC_c$	$R3TC_c$	VTC_c	STC_c	T	λ_v	λs	$Q1_c$	$Q2_c$	$Q3_c$	$T.Cost_c$
12501	18474	16871	11070	22140	0.018	1	1	2710	2710	2710	81056

Table 1 (d) With coordination /With out sharing ,only vendor keeps savings (retailers cost, vendor cost , supplier cost, total channel cost, vendor savings and vendor percentage savings).

$R1TC_{cws}$	$R2TC_{cws}$	$R3TC_{cws}$	VTC_{cws}	STC_{cws}	TC_{cws}	SPB_c	V_{SAV}	V_{SAV} %(100)
8485	12000	13416	-33475	80630	81056	58490	99312	1.508

Table 1 (e) With coordination/with sharing, all members share savings (retailers cost, vendor cost, supplier cost, supplier pay back to vendor, retailers discount per unit, total channel percentage savings).

$R1TC_{cs}$	$R2TC_{cs}$	$R3TC_{cs}$	VTC_{cs}	STC_{cs}	TC_{cs}	R1 Dis/u	R2 Dis/u	R3 Dis/u	T.C. SAV	T.C. SAV %(100)
3813	5393	6029	29587	36235	81056	0.0267	0.0431	0.0230	99312	0.5506

Case 2. Optimal order quantities, vendor savings in a identical three level supply chain (Supplier-Vendor-3 Retailers) with coordination for the case of maximum setup costs for the supplier and minimum for the retailers in the chain (S_S=400, S_V=200, S_{R1}=30, S_{R2}=40, S_{R3}=60) and holding costs (H_S=20, H_V=15, H_{R1}=6, H_{R2}=8, H_{R3}=12) with constant demand D1=D2=D3=150,000.

Table 2 (a) Without coordination (lot size multiplier for vendor and supplier, lot size for retailers)

λ_{v1}	λ_{v2}	λ_{v3}	λ_{S1}	λ_{S2}	λ_{S3}	$Q1_{wc}$	$Q2_{wc}$	$Q3_{wc}$
2	2	2	1	1	1	1225	1225	1225

Table 2 (b) Without Coordination (Retailers cost, vendor cost, supplier cost and total chain cost)

$R1TC_{wc}$	$R2TC_{wc}$	$R3TC_{wc}$	$V1TC_{wc}$	$V2TC_{wc}$	$V3TC_{wc}$	VTC_{wc}	$S1TC_{wc}$	$S2TC_{wc}$	$S3TC_{wc}$	STC_{wc}	$T.Cost_{wc}$
7348	9798	14697	21432	21432	21432	64296	24490	24490	24490	73470	169609

Table 2 (c) With coordination (retailers cost, vendor cost, supplier cost, time period, lot size multiplier for vendor and supplier, lot size for retailers and total cost).

$R1TC_c$	$R2TC_c$	$R3TC_c$	VTC_c	STC_c	T	λ_v	λ_S	$Q1_c$	$Q2_c$	$Q3_c$	$T.Cost_c$
10284	13712	20568	10299	20597	0.019	1	1	2913	2913	2913	75460

Table 2 (d) With coordination /With out sharing ,only vendor keeps savings (retailers cost, vendor cost , supplier cost, total channel cost, vendor savings and vendor percentage savings).

$R1TC_{cws}$	$R2TC_{cws}$	$R3TC_{cws}$	VTC_{cws}	STC_{cws}	TC_{cws}	SPB_c	V_{SAV}	V_{SAV} %(100)
7348	9798	14697	-29853	73470	75460	52873	94149	1.4643

Table 2 (e) With coordination/with sharing, all members share savings (retailers cost, vendor cost, supplier cost, supplier pay back to vendor, retailers discount per unit, total channel percentage savings).

$R1TC_{cs}$	$R2TC_{cs}$	$R3TC_{cs}$	VTC_{cs}	STC_{cs}	TC_{cs}	R1 Dis/u	R2 Dis/u	R3 Dis/u	T.C. SAV	T.C. SAV %(100)
3269	4359	6539	28606	32687	75460	0.01957	0.02609	0.03914	94149	0.5550

Case 3. Optimal order quantities, vendor savings in a non -identical three level supply chain (Supplier-Vendor-3 Retailers) with coordination for the case of maximum setup costs for the retailers and minimum for the supplier in the chain (S_S=30, S_V=200, S_{R1}=360, S_{R2}=390, S_{R3}=420) and holding costs (H_S=8, H_V=12, H_{R1}=12, H_{R2}=16, H_{R3}=20) with constant demand D1=D2=D3=150,000.

Table 3 (a) Without coordination (lot size multiplier for vendor and supplier, lot size for retailers)

λ_{v1}	λ_{v2}	λ_{v3}	λs_1	λs_2	λs_3	$Q1_{wc}$	$Q2_{wc}$	$Q3_{wc}$
1	1	1	1	1	1	3000	2704	2510

Table 3 (b) Without Coordination (Retailers cost, vendor cost, supplier cost and total chain cost)

$R1TC_{wc}$	$R2TC_{wc}$	$R3TC_{wc}$	$V1TC_{wc}$	$V2TC_{wc}$	$V3TC_{wc}$	VTC_{wc}	$S1TC_{wc}$	$S2TC_{wc}$	$S3TC_{wc}$	STC_{wc}	$T.Cost_{wc}$
36000	43267	50200	10000	11095	11952	33047	1500	1664	1793	4957	167471

Table 3 (c) With coordination (retailers cost, vendor cost, supplier cost, time period, lot size multiplier for vendor and supplier, lot size for retailers and total cost).

$R1TC_c$	$R2TC_c$	$R3TC_c$	VTC_c	STC_c	T	λ_v	λs	$Q1_c$	$Q2_c$	$Q3_c$	$T.Cost_c$
36000	43502	51003	9997	1500	0.020	1	1	3001	3001	3001	142002

Table 3 (d) With coordination /With out sharing ,only vendor keeps savings (retailers cost, vendor cost , supplier cost, total channel cost, vendor savings and vendor percentage savings).

$R1TC_{cws}$	$R2TC_{cws}$	$R3TC_{cws}$	VTC_{cws}	STC_{cws}	TC_{cws}	SPB_c	V_{SAV}	V_{SAV} %(100)
36000	43267	50200	7578	4957	142002	3457	25469	0.7706

Table 3 (e) With coordination/with sharing, all members share savings (retailers cost, vendor cost, supplier cost, supplier pay back to vendor, retailers discount per unit, total channel percentage savings).

$R1TC_{cs}$	$R2TC_{cs}$	$R3TC_{cs}$	VTC_{cs}	STC_{cs}	TC_{cs}	R1 Dis/u	R2 Dis/u	R3 Dis/u	T.C. SAV	T.C. SAV %(100)
30525	36687	42566	28021	4203	142002	0	0.001566	0.00535	25469	0.1520

Case 4. Optimal order quantities, vendor savings in a identical three level supply chain (Supplier-Vendor-3 Retailers) with coordination for the case of maximum setup costs for the retailers and minimum for the supplier in the chain (S_S=30, S_V=200, S_{R1}=360, S_{R2}=390, S_{R3}=420) and holding costs (H_S=8, H_V=12, H_{R1}=12, H_{R2}=13, H_{R3}=14) with constant demand D1=D2=D3=150,000.

Table 4 (a) Without coordination (lot size multiplier for vendor and supplier, lot size for retailers)

λ_{v1}	λ_{v2}	λ_{v3}	λ_{S1}	λ_{S2}	λ_{S3}	$Q1_{wc}$	$Q2_{wc}$	$Q3_{wc}$
1	1	1	1	1	1	3000	3000	3000

Table 4 (b) Without Coordination (Retailers cost, vendor cost, supplier cost and total chain cost)

$R1TC_{wc}$	$R2TC_{wc}$	$R3TC_{wc}$	$V1TC_{wc}$	$V2TC_{wc}$	$V3TC_{wc}$	VTC_{wc}	$S1TC_{wc}$	$S2TC_{wc}$	$S3TC_{wc}$	STC_{wc}	$T.Cost_{wc}$
36000	39000	42000	10000	10000	10000	30000	1500	1500	1500	4500	151500

Table 4 (c) With coordination (retailers cost, vendor cost, supplier cost, time period, lot size multiplier for vendor and supplier, lot size for retailers and total cost).

$R1TC_c$	$R2TC_c$	$R3TC_c$	VTC_c	STC_c	T	λ_v	λ_S	$Q1_c$	$Q2_c$	$Q3_c$	$T.Cost_c$
36144	39156	42168	9144	1372	0.021	1	1	3281	3281	3281	127984

Table 4 (d) With coordination /With out sharing ,only vendor keeps savings (retailers cost, vendor cost , supplier cost, total channel cost, vendor savings and vendor percentage savings).

$R1TC_{cws}$	$R2TC_{cws}$	$R3TC_{cws}$	VTC_{cws}	STC_{cws}	TC_{cws}	SPB_c	V_{SAV}	V_{SAV} %(100)
36000	39000	42000	6484	4500	127984	3128	23516	0.7838

Table 4 (e) With coordination/with sharing, all members share savings (retailers cost, vendor cost, supplier cost, supplier pay back to vendor, retailers discount per unit, total channel percentage savings).

$R1TC_{cs}$	$R2TC_{cs}$	$R3TC_{cs}$	VTC_{cs}	STC_{cs}	TC_{cs}	R1 Dis/u	R2 Dis/u	R3 Dis/u	T.C. SAV	T.C. SAV %(100)
30412	32946	35481	25343	3802	127984	0.00096	0.00104	0.00112	23516	0.1552

Case 5. Optimal order quantities, vendor savings in a non -identical three level supply chain (Supplier-Vendor-3 Retailers) with coordination for the case of maximum setup costs for the vendor and minimum for the retailers in the chain (S_S=200, S_V=400, S_{R1}=30, S_{R2}=40, S_{R3}=60) and holding costs (H_S=12, H_V=20, H_{R1}=8, H_{R2}=12, H_{R3}=10) with constant demand D1=D2=D3=150,000.

Table 5 (a) Without coordination (lot size multiplier for vendor and supplier, lot size for retailers)

λ_{v1}	λ_{v2}	λ_{v3}	λs_1	λs_2	λs_3	$Q1_{wc}$	$Q2_{wc}$	$Q3_{wc}$
2	3	2	1	1	1	1061	1000	1342

Table 5 (b) Without Coordination (Retailers cost, vendor cost, supplier cost and total chain cost)

$R1TC_{wc}$	$R2TC_{wc}$	$R3TC_{wc}$	$V1TC_{wc}$	$V2TC_{wc}$	$V3TC_{wc}$	VTC_{wc}	$S1TC_{wc}$	$S2TC_{wc}$	$S3TC_{wc}$	STC_{wc}	$T.Cost_{wc}$
8485	12000	13416	38885	40000	35775	114660	14138	10000	11177	35315	183876

Table 5 (c) With coordination (retailers cost, vendor cost, supplier cost, time period, lot size multiplier for vendor and supplier, lot size for retailers and total cost).

$R1TC_c$	$R2TC_c$	$R3TC_c$	VTC_c	STC_c	T	λ_v	λs	$Q1_c$	$Q2_c$	$Q3_c$	$T.Cost_c$
12501	18474	16871	22140	11070	0.018	1	1	2710	2710	2710	81056

Table 5 (d) With coordination /With out sharing ,only vendor keeps savings (retailers cost, vendor cost , supplier cost, total channel cost, vendor savings and vendor percentage savings).

$R1TC_{cws}$	$R2TC_{cws}$	$R3TC_{cws}$	VTC_{cws}	STC_{cws}	TC_{cws}	SPB_c	V_{SAV}	V_{SAV} %(100)
8485	12000	13416	11840	35315	81056	24245	102820	0.8967

Table 5 (e) With coordination/with sharing, all members share savings (retailers cost, vendor cost, supplier cost, supplier pay back to vendor, retailers discount per unit, total channel percentage savings).

$R1TC_{cs}$	$R2TC_{cs}$	$R3TC_{cs}$	VTC_{cs}	STC_{cs}	TC_{cs}	R1 Dis/u	R2 Dis/u	R3 Dis/u	T.C. SAV	T.C. SAV %(100)
3740	5290	5914	50544	15568	81056	0.0267	0.0431	0.0230	102820	0.5591

Case 6. Optimal order quantities, vendor savings in a identical three level supply chain (Supplier-Vendor-3 Retailers) with coordination for the case of maximum setup costs for the vendor and minimum for the retailers in the chain (S_S=200, S_V=400, S_{R1}=30, S_{R2}=40, S_{R3}=60) and holding costs (H_S=12, H_V=20, H_{R1}=9, H_{R2}=12, H_{R3}=18) with constant demand D1=D2=D3=150,000.

Table 6 (a) Without coordination (lot size multiplier for vendor and supplier, lot size for retailers)

λ_{v1}	λ_{v2}	λ_{v3}	λ_{S1}	λ_{S2}	λ_{S3}	$Q1_{wc}$	$Q2_{wc}$	$Q3_{wc}$
3	3	3	1	1	1	1000	1000	1000

Table 6 (b) Without Coordination (Retailers cost, vendor cost, supplier cost and total chain cost)

$R1TC_{wc}$	$R2TC_{wc}$	$R3TC_{wc}$	$V1TC_{wc}$	$V2TC_{wc}$	$V3TC_{wc}$	VTC_{wc}	$S1TC_{wc}$	$S2TC_{wc}$	$S3TC_{wc}$	STC_{wc}	$T.Cost_{wc}$
9000	12000	18000	40000	40000	40000	120000	10000	10000	10000	30000	189000

Table 6 (c) With coordination (retailers cost, vendor cost, supplier cost, time period, lot size multiplier for vendor and supplier, lot size for retailers and total cost).

$R1TC_c$	$R2TC_c$	$R3TC_c$	VTC_c	STC_c	T	λ_v	λ_S	$Q1_c$	$Q2_c$	$Q3_c$	$T.Cost_c$
12586	16781	25172	25253	12626	0.015	1	1	2376	2376	2376	92418

Table 6 (d) With coordination /With out sharing ,only vendor keeps savings (retailers cost, vendor cost , supplier cost, total channel cost, vendor savings and vendor percentage savings).

$R1TC_{cws}$	$R2TC_{cws}$	$R3TC_{cws}$	VTC_{cws}	STC_{cws}	TC_{cws}	SPB_c	V_{SAV}	V_{SAV} %(100)
9000	12000	18000	23418	30000	92418	17374	96582	0.8048

Table 6 (e) With coordination/with sharing, all membérs share savings (retailers cost, vendor cost, supplier cost, supplier pay back to vendor, retailers discount per unit, total channel percentage savings).

$R1TC_{cs}$	$R2TC_{cs}$	$R3TC_{cs}$	VTC_{cs}	STC_{cs}	TC_{cs}	R1 Dis/u	R2 Dis/u	R3 Dis/u	T.C. SAV	T.C. SAV %(100)
4401	5868	8802	58678	14670	92418	0.0239	0.0318	0.0478	96582	0.5110

Case 7. Optimal order quantities, vendor savings in a non -identical three level supply chain (Supplier-Vendor-3 Retailers) with coordination for the case of maximum setup costs for the retailers and minimum for the vendor in the chain (S_S=200, S_V=30, S_{R1}=360, S_{R2}=390, S_{R3}=420) and holding costs (H_S=12, H_V=8, H_{R1}=12, H_{R2}=16, H_{R3}=20) with constant demand D1=D2=D3=150,000.

Table 7 (a) Without coordination (lot size multiplier for vendor and supplier, lot size for retailers)

λ_{v1}	λ_{v2}	λ_{v3}	λs_1	λs_2	λs_3	$Q1_{wc}$	$Q2_{wc}$	$Q3_{wc}$
1	1	1	1	1	1	3000	2704	2510

Table 7 (b) Without Coordination (Retailers cost, vendor cost, supplier cost and total chain cost)

$R1TC_{wc}$	$R2TC_{wc}$	$R3TC_{wc}$	$V1TC_{wc}$	$V2TC_{wc}$	$V3TC_{wc}$	VTC_{wc}	$S1TC_{wc}$	$S2TC_{wc}$	$S3TC_{wc}$	STC_{wc}	$T.Cost_{wc}$
36000	43267	50200	1500	1664	1793	4957	10000	11095	11952	33047	167471

Table 7 (c) With coordination (retailers cost, vendor cost, supplier cost, time period, lot size multiplier for vendor and supplier, lot size for retailers and total cost).

$R1TC_c$	$R2TC_c$	$R3TC_c$	VTC_c	STC_c	T	λ_v	λs	$Q1_c$	$Q2_c$	$Q3_c$	$T.Cost_c$
36000	43502	51003	1500	9997	0.020	1	1	3001	3001	3001	142002

Table 7 (d) With coordination /With out sharing ,only vendor keeps savings (retailers cost, vendor cost , supplier cost, total channel cost, vendor savings and vendor percentage savings).

$R1TC_{cws}$	$R2TC_{cws}$	$R3TC_{cws}$	VTC_{cws}	STC_{cws}	TC_{cws}	SPB_c	V_{SAV}	V_{SAV} %(100)
36000	43267	50200	-20512	33047	142002	23050	25469	5.1379

Table 7 (e) With coordination/with sharing, all members share savings (retailers cost, vendor cost, supplier cost, supplier pay back to vendor, retailers discount per unit, total channel percentage savings).

$R1TC_{cs}$	$R2TC_{cs}$	$R3TC_{cs}$	VTC_{cs}	STC_{cs}	TC_{cs}	R1 Dis/u	R2 Dis/u	R3 Dis/u	T.C. SAV	T.C. SAV %(100)
30525	36687	42566	4203	28021	142002	0	0.00156	0.0053	25469	0.1520

Case 8. Optimal order quantities, vendor savings in a identical three level supply chain (Supplier-Vendor-3 Retailers) with coordination for the case of maximum setup costs for the retailers and minimum for the vendor in the chain (S_S=200, S_V=30, S_{R1}=360, S_{R2}=390, S_{R3}=420) and holding costs (H_S=12, H_V=8, H_{R1}=12, H_{R2}=13, H_{R3}=14) with constant demand D1=D2=D3=150,000.

Table 8 (a) Without coordination (lot size multiplier for vendor and supplier, lot size for retailers)

λ_{v1}	λ_{v2}	λ_{v3}	λ_{S1}	λ_{S2}	λ_{S3}	$Q1_{wc}$	$Q2_{wc}$	$Q3_{wc}$
1	1	1	1	1	1	3000	3000	3000

Table 8 (b) Without Coordination (Retailers cost, vendor cost, supplier cost and total chain cost)

$R1TC_{wc}$	$R2TC_{wc}$	$R3TC_{wc}$	$V1TC_{wc}$	$V2TC_{wc}$	$V3TC_{wc}$	VTC_{wc}	$S1TC_{wc}$	$S2TC_{wc}$	$S3TC_{wc}$	STC_{wc}	$T.Cost_{wc}$
36000	39000	42000	1500	1500	1500	4500	10000	10000	10000	30000	151500

Table 8 (c) With coordination (retailers cost, vendor cost, supplier cost, time period, lot size multiplier for vendor and supplier, lot size for retailers and total cost).

$R1TC_c$	$R2TC_c$	$R3TC_c$	VTC_c	STC_c	T	λ_v	λ_S	$Q1_c$	$Q2_c$	$Q3_c$	$T.Cost_c$
36144	39156	42168	1372	9144	0.021	1	1	3281	3281	3281	127984

Table 8 (d) With coordination /With out sharing ,only vendor keeps savings (retailers cost, vendor cost , supplier cost, total channel cost, vendor savings and vendor percentage savings).

$R1TC_{cws}$	$R2TC_{cws}$	$R3TC_{cws}$	VTC_{cws}	STC_{cws}	TC_{cws}	SPB_c	V_{SAV}	V_{SAV} %(100)
36000	39000	42000	-19016	30000	127984	20856	23516	5.225

Table 8 (e) With coordination/with sharing, all members share savings (retailers cost, vendor cost, supplier cost, supplier pay back to vendor, retailers discount per unit, total channel percentage savings).

$R1TC_{cs}$	$R2TC_{cs}$	$R3TC_{cs}$	VTC_{cs}	STC_{cs}	TC_{cs}	R1 Dis/u	R2 Dis/u	R3 Dis/u	T.C. SAV	T.C. SAV %(100)
30412	32946	35481	3802	25343	127984	0.00096	0.00104	0.00112	23516	0.1552

Case 9. Optimal order quantities, vendor savings in a non identical three level supply chain (Supplier-Vendor-3 Retailers) with coordination for the case of maximum setup costs for the supplier and minimum for the retailers in the chain (S_S=450, S_V=250, S_{R1}=50, S_{R2}=45, S_{R3}=40) and holding costs (H_S=70, H_V=50, H_{R1}=12, H_{R2}=10, H_{R3}=8) with constant demand D1=D2=D3=150,000.

Table 9 (a) Without coordination (lot size multiplier for vendor and supplier, lot size for retailers)

λ_{v1}	λ_{v2}	λ_{v3}	λ_{S1}	λ_{S2}	λ_{S3}	$Q1_{wc}$	$Q2_{wc}$	$Q3_{wc}$
1	1	1	1	1	1	1118	1162	1225

Table 9 (b) Without Coordination (Retailers cost, vendor cost, supplier cost and total chain cost)

$R1TC_{wc}$	$R2TC_{wc}$	$R3TC_{wc}$	$V1TC_{wc}$	$V2TC_{wc}$	$V3TC_{wc}$	VTC_{wc}	$S1TC_{wc}$	$S2TC_{wc}$	$S3TC_{wc}$	STC_{wc}	$T.Cost_{wc}$
13416	11619	9798	33542	32272	30612	96426	60376	58090	55102	173568	304827

Table 9 (c) With coordination (retailers cost, vendor cost, supplier cost, time period, lot size multiplier for vendor and supplier, lot size for retailers and total cost).

$R1TC_c$	$R2TC_c$	$R3TC_c$	VTC_c	STC_c	T	λ_v	λS	$Q1_c$	$Q2_c$	$Q3_c$	$T.Cost_c$
19956	16802	13649	12958	23324	0.019	1	1	2894	2894	2894	86689

Table 9 (d) With coordination /With out sharing ,only vendor keeps savings (retailers cost, vendor cost , supplier cost, total channel cost, vendor savings and vendor percentage savings).

$R1TC_{cws}$	$R2TC_{cws}$	$R3TC_{cws}$	VTC_{cws}	STC_{cws}	TC_{cws}	SPB_c	V_{SAV}	V_{SAV} %(100)
13416	11619	9798	-121712	173568	86689	150244	218138	2.2622

Table 9 (e) With coordination/with sharing, all members share savings (retailers cost, vendor cost, supplier cost, supplier pay back to vendor, retailers discount per unit, total channel percentage savings).

$R1TC_{cs}$	$R2TC_{cs}$	$R3TC_{cs}$	VTC_{cs}	STC_{cs}	TC_{cs}	R1 Dis/u	R2 Dis/u	R3 Dis/u	T.C. SAV	T.C. SAV %(100)
3815	3304	2786	27422	49361	86689	0.0436	0.0345	0.0256	218138	0.7156

Case 10. Optimal order quantities, vendor savings in a non identical three level supply chain (Supplier-Vendor-3 Retailers) with coordination for the case of maximum setup costs for the vendor and minimum for the supplier in the chain (S_S=50, S_V=450, S_{R1}=250, S_{R2}=270, S_{R3}=290) and holding costs (H_S=12, H_V=70, H_{R1}=50, H_{R2}=55, H_{R3}=60) with constant demand D1=D2=D3=150,000.

Table 10 (a) Without coordination (lot size multiplier for vendor and supplier, lot size for retailers)

λ_{v1}	λ_{v2}	λ_{v3}	λ_{S1}	λ_{S2}	λ_{S3}	$Q1_{wc}$	$Q2_{wc}$	$Q3_{wc}$
1	1	1	1	1	1	1225	1214	1204

Table 10 (b) Without Coordination (Retailers cost, vendor cost, supplier cost and total chain cost)

$R1TC_{wc}$	$R2TC_{wc}$	$R3TC_{wc}$	$V1TC_{wc}$	$V2TC_{wc}$	$V3TC_{wc}$	VTC_{wc}	$S1TC_{wc}$	$S2TC_{wc}$	$S3TC_{wc}$	STC_{wc}	$T.Cost_{wc}$
61237	66746	72250	55102	55601	56063	166766	6122	6178	6229	18529	385528

Table 10 (c) With coordination (retailers cost, vendor cost, supplier cost, time period, lot size multiplier for vendor and supplier, lot size for retailers and total cost).

$R1TC_c$	$R2TC_c$	$R3TC_c$	VTC_c	STC_c	T	λ_v	λ_S	$Q1_c$	$Q2_c$	$Q3_c$	$T.Cost_c$
62906	68712	74517	43661	4851	0.010	1	1	1546	1546	1546	254647

Table 10 (d) With coordination /With out sharing ,only vendor keeps savings (retailers cost, vendor cost , supplier cost, total channel cost, vendor savings and vendor percentage savings).

$R1TC_{cws}$	$R2TC_{cws}$	$R3TC_{cws}$	VTC_{cws}	STC_{cws}	TC_{cws}	SPB_c	V_{SAV}	V_{SAV} %(100)
61237	66746	72250	35885	18529	254647	13678	130881	0.7848

Table 10 (e) With coordination/with sharing, all members share savings (retailers cost, vendor cost, supplier cost, supplier pay back to vendor, retailers discount per unit, total channel percentage savings).

$R1TC_{cs}$	$R2TC_{cs}$	$R3TC_{cs}$	VTC_{cs}	STC_{cs}	TC_{cs}	R1 Dis/u	R2 Dis/u	R3 Dis/u	T.C. SAV	T.C. SAV %(100)
40448	44087	47722	110151	12239	254647	0.01112	0.01310	0.01511	130881	0.3394

Case 11. Optimal order quantities, vendor savings in a non identical three level supply chain (Supplier-Vendor-3 Retailers) with coordination for the case of maximum setup costs for the retailers and minimum for the vendor in the chain (S_S=250, S_V=450, S_{R1}=50, S_{R2}=45, S_{R3}=40) and holding costs (H_S=50, H_V=70, H_{R1}=12, H_{R2}=10, H_{R3}=8) with constant demand D1=D2=D3=150,000.

Table 11 (a) Without coordination (lot size multiplier for vendor and supplier, lot size for retailers)

λ_{v1}	λ_{v2}	λ_{v3}	λ_{S1}	λ_{S2}	λ_{S3}	$Q1_{wc}$	$Q2_{wc}$	$Q3_{wc}$
1	1	1	1	1	1	1118	1162	1225

Table 11 (b) Without Coordination (Retailers cost, vendor cost, supplier cost and total chain cost)

$R1TC_{wc}$	$R2TC_{wc}$	$R3TC_{wc}$	$V1TC_{wc}$	$V2TC_{wc}$	$V3TC_{wc}$	VTC_{wc}	$S1TC_{wc}$	$S2TC_{wc}$	$S3TC_{wc}$	STC_{wc}	$T.Cost_{wc}$
13416	11619	9798	60376	58090	55102	173568	33542	32272	30612	96426	304827

Table 11 (c) With coordination (retailers cost, vendor cost, supplier cost, time period, lot size multiplier for vendor and supplier, lot size for retailers and total cost).

$R1TC_c$	$R2TC_c$	$R3TC_c$	VTC_c	STC_c	T	λ_v	λ_S	$Q1_c$	$Q2_c$	$Q3_c$	$T.Cost_c$
19956	16802	13649	23324	12958	0.01929	1	1	2894	2894	2894	86689

Table 11 (d) With coordination /With out sharing ,only vendor keeps savings (retailers cost, vendor cost , supplier cost, total channel cost, vendor savings and vendor percentage savings).

$R1TC_{cws}$	$R2TC_{cws}$	$R3TC_{cws}$	VTC_{cws}	STC_{cws}	TC_{cws}	SPB_c	V_{SAV}	V_{SAV} %(100)
13416	11619	9798	-44570	96426	86689	83468	218138	1.256

Table 11 (e) With coordination/with sharing, all members share savings (retailers cost, vendor cost, supplier cost, supplier pay back to vendor, retailers discount per unit, total channel percentage savings).

$R1TC_{cs}$	$R2TC_{cs}$	$R3TC_{cs}$	VTC_{cs}	STC_{cs}	TC_{cs}	R1 Dis/u	R2 Dis/u	R3 Dis/u	T.C. SAV	T.C. SAV %(100)
3815	3304	2786	49361	27422	86689	0.0436	0.03455	0.02567	218138	0.7156

Case 12. Optimal order quantities, vendor savings in a identical three level supply chain (Supplier-Vendor-3 Retailers) with coordination for the case of maximum setup costs for the supplier and minimum for the retailers in the chain (S_S=400, S_V=200, S_{R1}=30, S_{R2}=30, S_{R3}=30) and holding costs (H_S=10, H_V=12, H_{R1}=16, H_{R2}=16, H_{R3}=16) with constant demand D1=D2=D3=150,000.

Table 12 (a) Without coordination (lot size multiplier for vendor and supplier, lot size for retailers)

λ_{v1}	λ_{v2}	λ_{v3}	λ_{S1}	λ_{S2}	λ_{S3}	$Q1_{wc}$	$Q2_{wc}$	$Q3_{wc}$
3	3	3	1	2	2	750	750	750

Table 12 (b) Without Coordination (Retailers cost, vendor cost, supplier cost and total chain cost)

$R1TC_{wc}$	$R2TC_{wc}$	$R3TC_{wc}$	$V1TC_{wc}$	$V2TC_{wc}$	$V3TC_{wc}$	VTC_{wc}	$S1TC_{wc}$	$S2TC_{wc}$	$S3TC_{wc}$	STC_{wc}	$T.Cost_{wc}$
12000	12000	12000	22333	22333	22333	66999	26667	24583	24583	75833	178832

Table 12 (c) With coordination (retailers cost, vendor cost, supplier cost, time period, lot size multiplier for vendor and supplier, lot size for retailers and total cost).

$R1TC_c$	$R2TC_c$	$R3TC_c$	VTC_c	STC_c	T	λ_v	λ_S	$Q1_c$	$Q2_c$	$Q3_c$	$T.Cost_c$
13282	13282	13282	33996	25295	0.007	2	1	1186	1186	1186	99137

Table 12 (d) With coordination /With out sharing ,only vendor keeps savings (retailers cost, vendor cost , supplier cost, total channel cost, vendor savings and vendor percentage savings).

$R1TC_{cws}$	$R2TC_{cws}$	$R3TC_{cws}$	VTC_{cws}	STC_{cws}	TC_{cws}	SPB_c	V_{SAV}	V_{SAV} %(100)
12000	12000	12000	-12696	75833	99137	50538	79695	1.1894

Table12 (e) With coordination/with sharing, all members share savings (retailers cost, vendor cost, supplier cost, supplier pay back to vendor, retailers discount per unit, total channel percentage savings).

$R1TC_{cs}$	$R2TC_{cs}$	$R3TC_{cs}$	VTC_{cs}	STC_{cs}	TC_{cs}	R1 Dis/u	R2 Dis/u	R3 Dis/u	T.C. SAV	T.C. SAV %(100)
6652	6652	6652	37141	42039	99137	0.00854	0.00854	0.00854	79695	0.4456

Appendix-II

Table (A) Channel Savings Results of 252 Experimental Runs

Exp#	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	y
1	50000	100000	150000	450	250	50	45	40	70	50	12	10	8	172389
2	150000	200000	250000	450	250	50	45	40	70	50	12	10	8	249993
3	250000	300000	350000	450	250	50	45	40	70	50	12	10	8	307530
4	350000	400000	450000	450	250	50	45	40	70	50	12	10	8	355620
5	450000	500000	550000	450	250	50	45	40	70	50	12	10	8	397902
6	550000	600000	650000	450	250	50	45	40	70	50	12	10	8	435886
7	650000	700000	750000	450	250	50	45	40	70	50	12	10	8	470985
8	750000	800000	850000	450	250	50	45	40	70	50	12	10	8	503629
9	850000	900000	950000	450	250	50	45	40	70	50	12	10	8	534230
10	950000	1000000	1050000	450	250	50	45	40	70	50	12	10	8	563106
11	50000	100000	150000	50	250	450	470	490	12	50	70	80	90	32230
12	150000	200000	250000	50	250	450	470	490	12	50	70	80	90	73767
13	250000	300000	350000	50	250	450	470	490	12	50	70	80	90	94749
14	350000	400000	450000	50	250	450	470	490	12	50	70	80	90	110888
15	450000	500000	550000	50	250	450	470	490	12	50	70	80	90	124677
16	550000	600000	650000	50	250	450	470	490	12	50	70	80	90	136951
17	650000	700000	750000	50	250	450	470	490	12	50	70	80	90	148139
18	750000	800000	850000	50	250	450	470	490	12	50	70	80	90	158578
19	850000	900000	950000	50	250	450	470	490	12	50	70	80	90	168330
20	950000	1000000	1050000	50	250	450	470	490	12	50	70	80	90	177549
21	50000	100000	150000	50	450	250	270	290	12	70	50	55	60	97336
22	150000	200000	250000	50	450	250	270	290	12	70	50	55	60	148310
23	250000	300000	350000	50	450	250	270	290	12	70	50	55	60	183509
24	350000	400000	450000	50	450	250	270	290	12	70	50	55	60	212570
25	450000	500000	550000	50	450	250	270	290	12	70	50	55	60	238098
26	550000	600000	650000	50	450	250	270	290	12	70	50	55	60	261089
27	650000	700000	750000	50	450	250	270	290	12	70	50	55	60	282114
28	750000	800000	850000	50	450	250	270	290	12	70	50	55	60	301773
29	850000	900000	950000	50	450	250	270	290	12	70	50	55	60	320213
30	950000	1000000	1050000	50	450	250	270	290	12	70	50	55	60	337605
31	50000	100000	150000	250	450	50	45	40	50	70	12	10	8	172389
32	150000	200000	250000	250	450	50	45	40	50	70	12	10	8	249993
33	250000	300000	350000	250	450	50	45	40	50	70	12	10	8	307530
34	350000	400000	450000	250	450	50	45	40	50	70	12	10	8	355620
35	450000	500000	550000	250	450	50	45	40	50	70	12	10	8	397902
36	550000	600000	650000	250	450	50	45	40	50	70	12	10	8	435886
37	650000	700000	750000	250	450	50	45	40	50	70	12	10	8	470985
38	750000	800000	850000	250	450	50	45	40	50	70	12	10	8	503629
39	850000	900000	950000	250	450	50	45	40	50	70	12	10	8	534230
40	950000	1000000	1050000	250	450	50	45	40	50	70	12	10	8	563106

Exp#	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	y
41	50000	100000	150000	250	50	450	470	490	50	12	70	80	90	32230
42	150000	200000	250000	250	50	450	470	490	50	12	70	80	90	73767
43	250000	300000	350000	250	50	450	470	490	50	12	70	80	90	94749
44	350000	400000	450000	250	50	450	470	490	50	12	70	80	90	110888
45	450000	500000	550000	250	50	450	470	490	50	12	70	80	90	124677
46	550000	600000	650000	250	50	450	470	490	50	12	70	80	90	136951
47	650000	700000	750000	250	50	450	470	490	50	12	70	80	90	148139
48	750000	800000	850000	250	50	450	470	490	50	12	70	80	90	158578
49	850000	900000	950000	250	50	450	470	490	50	12	70	80	90	168330
50	950000	1000000	1050000	250	50	450	470	490	50	12	70	80	90	177549
51	50000	100000	150000	450	50	250	270	290	70	12	50	55	60	97336
52	150000	200000	250000	450	50	250	270	290	70	12	50	55	60	148552
53	250000	300000	350000	450	50	250	270	290	70	12	50	55	60	185567
54	350000	400000	450000	450	50	250	270	290	70	12	50	55	60	215446
55	450000	500000	550000	450	50	250	270	290	70	12	50	55	60	241503
56	550000	600000	650000	450	50	250	270	290	70	12	50	55	60	264888
57	650000	700000	750000	450	50	250	270	290	70	12	50	55	60	286237
58	750000	800000	850000	450	50	250	270	290	70	12	50	55	60	306179
59	850000	900000	950000	450	50	250	270	290	70	12	50	55	60	324877
60	950000	1000000	1050000	450	50	250	270	290	70	12	50	55	60	342504
61	50000	100000	150000	250	450	125	130	140	50	90	20	25	35	149985
62	150000	200000	250000	250	450	125	130	140	50	90	20	25	35	218959
63	250000	300000	350000	250	450	125	130	140	50	90	20	25	35	269603
64	350000	400000	450000	250	450	125	130	140	50	90	20	25	35	311839
65	450000	500000	550000	250	450	125	130	140	50	90	20	25	35	348941
66	550000	600000	650000	250	450	125	130	140	50	90	20	25	35	382487
67	650000	700000	750000	250	450	125	130	140	50	90	20	25	35	413296
68	750000	800000	850000	250	450	125	130	140	50	90	20	25	35	441824
69	850000	900000	950000	250	450	125	130	140	50	90	20	25	35	468680
70	950000	1000000	1050000	250	450	125	130	140	50	90	20	25	35	494110
71	50000	100000	150000	450	250	125	130	140	90	50	20	25	35	149985
72	150000	200000	250000	450	250	125	130	140	90	50	20	25	35	218959
73	250000	300000	350000	450	250	125	130	140	90	50	20	25	35	269603
74	350000	400000	450000	450	250	125	130	140	90	50	20	25	35	311839
75	450000	500000	550000	450	250	125	130	140	90	50	20	25	35	348941
76	550000	600000	650000	450	250	125	130	140	90	50	20	25	35	382487
77	650000	700000	750000	450	250	125	130	140	90	50	20	25	35	413296
78	750000	800000	850000	450	250	125	130	140	90	50	20	25	35	441824
79	850000	900000	950000	450	250	125	130	140	90	50	20	25	35	468680
80	950000	1000000	1050000	450	250	125	130	140	90	50	20	25	35	494110
81	100000	100000	100000	450	250	50	50	50	70	50	12	12	12	184642
82	200000	200000	200000	450	250	50	50	50	70	50	12	12	12	261171
83	300000	300000	300000	450	250	50	50	50	70	50	12	12	12	319905
84	400000	400000	400000	450	250	50	50	50	70	50	12	12	12	369290
85	500000	500000	500000	450	250	50	50	50	70	50	12	12	12	413009

Exp#	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	y
86	600000	600000	600000	450	250	50	50	50	70	50	12	12	12	452380
87	700000	700000	700000	450	250	50	50	50	70	50	12	12	12	488669
88	800000	800000	800000	450	250	50	50	50	70	50	12	12	12	522342
89	900000	900000	900000	450	250	50	50	50	70	50	12	12	12	553932
90	1000000	1000000	1000000	450	250	50	50	50	70	50	12	12	12	583936
91	100000	100000	100000	50	250	450	450	450	12	50	70	70	70	54234
92	200000	200000	200000	50	250	450	450	450	12	50	70	70	70	76677
93	300000	300000	300000	50	250	450	450	450	12	50	70	70	70	93942
94	400000	400000	400000	50	250	450	450	450	12	50	70	70	70	108466
95	500000	500000	500000	50	250	450	450	450	12	50	70	70	70	121318
96	600000	600000	600000	50	250	450	450	450	12	50	70	70	70	132894
97	700000	700000	700000	50	250	450	450	450	12	50	70	70	70	143508
98	800000	800000	800000	50	250	450	450	450	12	50	70	70	70	153427
99	900000	900000	900000	50	250	450	450	450	12	50	70	70	70	162705
100	1000000	1000000	1000000	50	250	450	450	450	12	50	70	70	70	171504
101	100000	100000	100000	50	450	250	250	250	12	70	50	50	50	106349
102	200000	200000	200000	50	450	250	250	250	12	70	50	50	50	150431
103	300000	300000	300000	50	450	250	250	250	12	70	50	50	50	184212
104	400000	400000	400000	50	450	250	250	250	12	70	50	50	50	212700
105	500000	500000	500000	50	450	250	250	250	12	70	50	50	50	237814
106	600000	600000	600000	50	450	250	250	250	12	70	50	50	50	260575
107	700000	700000	700000	50	450	250	250	250	12	70	50	50	50	281342
108	800000	800000	800000	50	450	250	250	250	12	70	50	50	50	300864
109	900000	900000	900000	50	450	250	250	250	12	70	50	50	50	319050
110	1000000	1000000	1000000	50	450	250	250	250	12	70	50	50	50	336352
111	100000	100000	100000	250	450	50	50	50	50	70	12	12	12	184642
112	200000	200000	200000	250	450	50	50	50	50	70	12	12	12	261171
113	300000	300000	300000	250	450	50	50	50	50	70	12	12	12	319905
114	400000	400000	400000	250	450	50	50	50	50	70	12	12	12	369290
115	500000	500000	500000	250	450	50	50	50	50	70	12	12	12	413009
116	600000	600000	600000	250	450	50	50	50	50	70	12	12	12	452380
117	700000	700000	700000	250	450	50	50	50	50	70	12	12	12	488669
118	800000	800000	800000	250	450	50	50	50	50	70	12	12	12	522342
119	900000	900000	900000	250	450	50	50	50	50	70	12	12	12	553932
120	1000000	1000000	1000000	250	450	50	50	50	50	70	12	12	12	583936
121	100000	100000	100000	250	50	450	450	450	50	12	70	70	70	54234
122	200000	200000	200000	250	50	450	450	450	50	12	70	70	70	76677
123	300000	300000	300000	250	50	450	450	450	50	12	70	70	70	93942
124	400000	400000	400000	250	50	450	450	450	50	12	70	70	70	108466
125	500000	500000	500000	250	50	450	450	450	50	12	70	70	70	121318
126	600000	600000	600000	250	50	450	450	450	50	12	70	70	70	132894
127	700000	700000	700000	250	50	450	450	450	50	12	70	70	70	143508
128	800000	800000	800000	250	50	450	450	450	50	12	70	70	70	153427
129	900000	900000	900000	250	50	450	450	450	50	12	70	70	70	162705
130	1000000	1000000	1000000	250	50	450	450	450	50	12	70	70	70	171504

Exp#	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	y
131	100000	100000	100000	450	50	250	250	250	70	12	50	50	50	107127
132	200000	200000	200000	450	50	250	250	250	70	12	50	50	50	151531
133	300000	300000	300000	450	50	250	250	250	70	12	50	50	50	185561
134	400000	400000	400000	450	50	250	250	250	70	12	50	50	50	214254
135	500000	500000	500000	450	50	250	250	250	70	12	50	50	50	239553
136	600000	600000	600000	450	50	250	250	250	70	12	50	50	50	262478
137	700000	700000	700000	450	50	250	250	250	70	12	50	50	50	283398
138	800000	800000	800000	450	50	250	250	250	70	12	50	50	50	303062
139	900000	900000	900000	450	50	250	250	250	70	12	50	50	50	321381
140	1000000	1000000	1000000	450	50	250	250	250	70	12	50	50	50	338808
141	100000	100000	100000	450	250	50	50	50	70	50	12	10	8	167764
142	200000	200000	200000	450	250	50	50	50	70	50	12	10	8	237292
143	300000	300000	300000	450	250	50	50	50	70	50	12	10	8	290639
144	400000	400000	400000	450	250	50	50	50	70	50	12	10	8	335533
145	500000	500000	500000	450	250	50	50	50	70	50	12	10	8	375181
146	600000	600000	600000	450	250	50	50	50	70	50	12	10	8	410981
147	700000	700000	700000	450	250	50	50	50	70	50	12	10	8	443897
148	800000	800000	800000	450	250	50	50	50	70	50	12	10	8	474583
149	900000	900000	900000	450	250	50	50	50	70	50	12	10	8	503298
150	1000000	1000000	1000000	450	250	50	50	50	70	50	12	10	8	530523
151	100000	100000	100000	450	250	50	45	40	70	50	10	10	10	179711
152	200000	200000	200000	450	250	50	45	40	70	50	10	10	10	254109
153	300000	300000	300000	450	250	50	45	40	70	50	10	10	10	311282
154	400000	400000	400000	450	250	50	45	40	70	50	10	10	10	359414
155	500000	500000	500000	450	250	50	45	40	70	50	10	10	10	401847
156	600000	600000	600000	450	250	50	45	40	70	50	10	10	10	440176
157	700000	700000	700000	450	250	50	45	40	70	50	10	10	10	475456
158	800000	800000	800000	450	250	50	45	40	70	50	10	10	10	508298
159	900000	900000	900000	450	250	50	45	40	70	50	10	10	10	539123
160	1000000	1000000	1000000	450	250	50	45	40	70	50	10	10	10	568313
161	100000	100000	100000	250	50	150	150	150	50	12	30	35	40	68585
162	200000	200000	200000	250	50	150	150	150	50	12	30	35	40	97007
163	300000	300000	300000	250	50	150	150	150	50	12	30	35	40	118788
164	400000	400000	400000	250	50	150	150	150	50	12	30	35	40	137168
165	500000	500000	500000	250	50	150	150	150	50	12	30	35	40	153400
166	600000	600000	600000	250	50	150	150	150	50	12	30	35	40	168031
167	700000	700000	700000	250	50	150	150	150	50	12	30	35	40	181496
168	800000	800000	800000	250	50	150	150	150	50	12	30	35	40	194022
169	900000	900000	900000	250	50	150	150	150	50	12	30	35	40	205791
170	1000000	1000000	1000000	250	50	150	150	150	50	12	30	35	40	216884
171	100000	100000	100000	250	50	150	170	190	50	12	30	30	30	59787
172	200000	200000	200000	250	50	150	170	190	50	12	30	30	30	84539
173	300000	300000	300000	250	50	150	170	190	50	12	30	30	30	103563
174	400000	400000	400000	250	50	150	170	190	50	12	30	30	30	119581
175	500000	500000	500000	250	50	150	170	190	50	12	30	30	30	133697

Exp#	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	y
176	600000	600000	600000	250	50	150	170	190	50	12	30	30	30	146452
177	700000	700000	700000	250	50	150	170	190	50	12	30	30	30	158165
178	800000	800000	800000	250	50	150	170	190	50	12	30	30	30	169131
179	900000	900000	900000	250	50	150	170	190	50	12	30	30	30	179370
180	1000000	1000000	1000000	250	50	150	170	190	50	12	30	30	30	189065
181	100000	100000	100000	250	50	150	150	170	50	12	30	30	40	65317
182	200000	200000	200000	250	50	150	150	170	50	12	30	30	40	92384
183	300000	300000	300000	250	50	150	150	170	50	12	30	30	40	113141
184	400000	400000	400000	250	50	150	150	170	50	12	30	30	40	130637
185	500000	500000	500000	250	50	150	150	170	50	12	30	30	40	146048
186	600000	600000	600000	250	50	150	150	170	50	12	30	30	40	160042
187	700000	700000	700000	250	50	150	150	170	50	12	30	30	40	172820
188	800000	800000	800000	250	50	150	150	170	50	12	30	30	40	184767
189	900000	900000	900000	250	50	150	150	170	50	12	30	30	40	195957
190	1000000	1000000	1000000	250	50	150	150	170	50	12	30	30	40	206596
191	100000	100000	100000	250	450	50	50	45	50	70	10	10	12	177683
192	200000	200000	200000	250	450	50	50	45	50	70	10	10	12	251284
193	300000	300000	300000	250	450	50	50	45	50	70	10	10	12	307763
194	400000	400000	400000	250	450	50	50	45	50	70	10	10	12	355370
195	500000	500000	500000	250	450	50	50	45	50	70	10	10	12	397363
196	600000	600000	600000	250	450	50	50	45	50	70	10	10	12	435326
197	700000	700000	700000	250	450	50	50	45	50	70	10	10	12	470096
198	800000	800000	800000	250	450	50	50	45	50	70	10	10	12	502663
199	900000	900000	900000	250	450	50	50	45	50	70	10	10	12	533052
200	1000000	1000000	1000000	250	450	50	50	45	50	70	10	10	12	561882
201	100000	100000	100000	250	450	50	50	50	50	70	12	10	8	167764
202	200000	200000	200000	250	450	50	50	50	50	70	12	10	8	237292
203	300000	300000	300000	250	450	50	50	50	50	70	12	10	8	290639
204	400000	400000	400000	250	450	50	50	50	50	70	12	10	8	335533
205	500000	500000	500000	250	450	50	50	50	50	70	12	10	8	375181
206	600000	600000	600000	250	450	50	50	50	50	70	12	10	8	410981
207	700000	700000	700000	250	450	50	50	50	50	70	12	10	8	443897
208	800000	800000	800000	250	450	50	50	50	50	70	12	10	8	474583
209	900000	900000	900000	250	450	50	50	50	50	70	12	10	8	503298
210	1000000	1000000	1000000	250	450	50	50	50	50	70	12	10	8	530523
211	100000	100000	100000	250	450	125	125	125	50	90	25	25	25	158014
212	200000	200000	200000	250	450	125	125	125	50	90	25	25	25	223510
213	300000	300000	300000	250	450	125	125	125	50	90	25	25	25	273704
214	400000	400000	400000	250	450	125	125	125	50	90	25	25	25	316030
215	500000	500000	500000	250	450	125	125	125	50	90	25	25	25	353347
216	600000	600000	600000	250	450	125	125	125	50	90	25	25	25	387157
217	700000	700000	700000	250	450	125	125	125	50	90	25	25	25	418022
218	800000	800000	800000	250	450	125	125	125	50	90	25	25	25	447022
219	900000	900000	900000	250	450	125	125	125	50	90	25	25	25	474046
220	1000000	1000000	1000000	250	450	125	125	125	50	90	25	25	25	499747

Exp#	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	y
221	100000	100000	100000	450	250	125	125	125	90	50	25	25	25	158014
222	200000	200000	200000	450	250	125	125	125	90	50	25	25	25	223510
223	300000	300000	300000	450	250	125	125	125	90	50	25	25	25	273703
224	400000	400000	400000	450	250	125	125	125	90	50	25	25	25	316030
225	500000	500000	500000	450	250	125	125	125	90	50	25	25	25	353347
226	600000	600000	600000	450	250	125	125	125	90	50	25	25	25	387157
227	700000	700000	700000	450	250	125	125	125	90	50	25	25	25	418022
228	800000	800000	800000	450	250	125	125	125	90	50	25	25	25	447022
229	900000	900000	900000	450	250	125	125	125	90	50	25	25	25	474046
230	1000000	1000000	1000000	450	250	125	125	125	90	50	25	25	25	499747
231	100000	100000	100000	250	450	125	125	135	50	90	25	25	35	164656
232	200000	200000	200000	250	450	125	125	135	50	90	25	25	35	232857
233	300000	300000	300000	250	450	125	125	135	50	90	25	25	35	285174
234	400000	400000	400000	250	450	125	125	135	50	90	25	25	35	329218
235	500000	500000	500000	250	450	125	125	135	50	90	25	25	35	368123
236	600000	600000	600000	250	450	125	125	135	50	90	25	25	35	403355
237	700000	700000	700000	250	450	125	125	135	50	90	25	25	35	435510
238	800000	800000	800000	250	450	125	125	135	50	90	25	25	35	465714
239	900000	900000	900000	250	450	125	125	135	50	90	25	25	35	493875
240	1000000	1000000	1000000	250	450	125	125	135	50	90	25	25	35	520675
241	150000	150000	150000	400	200	30	40	60	20	15	8	12	10	99312
242	150000	150000	150000	400	200	30	40	60	20	15	6	8	12	94149
243	150000	150000	150000	30	200	360	390	420	8	12	12	16	20	25469
244	150000	150000	150000	30	200	360	390	420	8	12	12	13	14	23516
245	150000	150000	150000	200	400	30	40	60	12	20	8	12	10	102820
246	150000	150000	150000	200	400	30	40	60	12	20	9	12	18	96582
247	150000	150000	150000	200	60	360	390	420	12	8	12	16	20	25469
248	150000	150000	150000	200	30	360	390	420	12	8	12	13	14	23516
249	150000	150000	150000	450	250	50	45	40	70	50	12	10	8	218138
250	150000	150000	150000	50	450	250	270	290	12	70	50	55	60	130881
251	150000	150000	150000	250	450	50	45	40	50	70	12	10	8	218138
252	150000	150000	150000	400	200	30	30	30	10	12	16	16	16	79695

Where

y	Total Savings in the chain due to coordination
x_1	Annual demand of retailer 1
x_2	Annual demand of retailer 2
x_3	Annual demand of retailer 3
x_4	Setup cost of Supplier
x_5	Setup cost of Vendor
x_6	Setup cost of Retailer 1
x_7	Setup cost of Retailer 2
x_8	Setup cost of Retailer 3
x_9	Holding cost of Supplier
x_{10}	Holding cost of Vendor
x_{11}	Holding cost of Retailer 1
x_{12}	Holding cost of Retailer 2
x_{13}	Holding cost of Retailer 3

Table (B) Summary Output of Regression Analysis

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.964210639
R Square	0.929702156
Adjusted R Square	0.925862358
Standard Error	40472.58971
Observations	252

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	13	5.15586E+12	3.97E+11	242.122662	4.3048E-129
Residual	238	3.89851E+11	1.64E+09		
Total	251	5.54571E+12			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-117113.0207	23749.07737	-4.93127	1.5335E-06	-163898.3163	-70327.73	-163898.32	-70327.7251
X Variable1 (A.Demand R1)	-0.459113513	186934.8845	-2.5E-06	0.99999804	-368259.1372	368258.22	-368259.14	368258.219
X Variable 2 (A.Demand R2)	1.02079473	373869.769	2.73E-06	0.99999782	-736516.3353	736518.38	-736516.34	736518.377
X Variable 3 (A.Demand R3)	-0.258846224	186934.8845	-1.4E-06	0.9999989	-368258.9369	368258.42	-368258.94	368258.419
X Variable 4 (S.Cost Supp.)	415.2471742	59.37995348	6.993053	2.6991E-11	298.2696329	532.22472	298.269633	532.224715
X Variable 5 (S.Cost Vend.)	416.5812292	75.36983711	5.527161	8.5281E-08	268.1038776	565.05858	268.103878	565.058581
X Variable 6 (S.Cost R1)	-2290.906681	1184.711139	-1.93373	0.05433265	-4624.76833	42.954968	-4624.7683	42.9549683
X Variable 7 (S.Cost R2)	5263.053031	2257.785679	2.331068	0.02058579	815.2520135	9710.854	815.252013	9710.85405
X Variable 8 (S.Cost R3)	-2928.573697	1138.138184	-2.57313	0.0106855	-5170.687384	-686.46	-5170.6874	-686.46001
X Variable 9 (H.Cost Supp.)	421.325001	346.8367832	1.214764	0.22565975	-261.9378133	1104.5878	-261.93781	1104.58782
X Variable 10 (H.Cost Vend.)	424.0220177	399.3030025	1.061905	0.28935497	-362.5983942	1210.6424	-362.59839	1210.64243
X Variable 11 (H.Cost R1)	2208.848216	2400.891274	0.920012	0.35849815	-2520.868492	6938.5649	-2520.8685	6938.56492
X Variable 12 (H.Cost R2)	-5443.109741	4003.613981	-1.35955	0.17525932	-13330.16408	2443.9446	-13330.164	2443.9446
X Variable 13 (H.Cost R3)	1957.124858	1878.48063	1.041866	0.29853104	-1743.45139	5657.7011	-1743.4514	5657.70111