

# MANAGING UNCERTAINTIES OF INVENTORY CONTROL IN A SUPPLY CHAIN

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of the requirement for the award of the degree of*  
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*in*  
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*by*  
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# CERTIFICATE

This is to certify that the thesis entitled “**MANAGING UNCERTAINTIES OF INVENTORY CONTROL IN A SUPPLY CHAIN**” being submitted by **Dharamvir Mangal**, in fulfillment of the requirement for the award of degree of *Doctor of Philosophy in Mechanical Engineering*, has been carried out under my supervision and guidance.

The matter embodied in this thesis has not been submitted, in part or in full, to any other university or institute for the award of any degree, diploma or certificate.

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## SYNOPSIS

Demanding competition in today's global markets, introduction of products with short life cycles, and the discriminating expectations of customers have forced business enterprises to invest in, and focus attention on their supply chains. Supply chain management has increasingly become an inevitable challenge to most companies to be continuously survived and prospered in the global chain-based competitive environment. Facing more demanding consumers, every chain member has to figure out how to increase flexibility so as to sustain good customer service while controlling or even better decreasing relevant costs from an entire chain standpoint. Increasing competitive pressures and market globalization are forcing firms to develop supply chains that can quickly respond to customer needs. In the last couple of decades, the numbers of products offered to the market have generally exploded. At the same time, the product life-time has decreased significantly. The combination of these two trends leads to increase inaccuracy of the demand forecasts, leading to firms facing an increased demand uncertainty, resulting, increase in inventory levels. In a supply chain, the inventory control problem is very thorny and challenging because the planner needs to judge several interacting factors, for example, supply chain structures, coordination levels, and information sharing processes. The inventory control policy used by each personage is also an important factor because it affects the inventory replenishment process of the upstream entity. In general, inventory levels are affected by customer service expectations, demand and lead-time uncertainties, and the liveness of the supply chain. Inventories provide some sanctuary against fluctuations in the level of customer demand, there is concern that they may reduce the capacity of supply chains to respond to changes in the nature of that demand. Due to demand uncertainty inventory investments can be very high in such supply chain systems. A commonly used strategy to introduce flexibility and overcome uncertainties in the system is to establish transshipment links between locations at the same stratum. Lateral transshipment is defined as a local warehouse, which provides stocked items to another local warehouse, which is out of stock or to prevent out of stock occurrences. Transshipments provide an effective mechanism for correcting discrepancies between the locations' observed demand and their available inventory. In such a case, the adjoining location can typically provide the required

products faster than the original supplier. Since the cost of transshipment is generally lower than both the stock-out cost and the cost of an emergency delivery from the central warehouse, and transshipment time is shorter than the regular replenishment lead-time, the stocking locations successfully pool their resources to reduce the risk of shortages and provide better service at lower cost. By allowing transshipments among locations better customer service can be achieved with retained inventory levels and with lesser associated cost. As a result, transshipments can lead to cost reductions and improved service without increasing inventory levels in the supply chain. Moreover, since transshipments enable the sharing of stock among locations, they naturally lead to harmonized replenishment policies across locations, thereby avoiding excessive procurement costs. The purpose of this work is to walk around the role of lateral transshipment in overcoming the qualms of demand and lead-time for controlling inventory and associated costs within a supply chain. It also aims concerning understanding about the retailer- retailer partnership in a supply chain framework.

India is a budding country, and interestingly, there has been a mounting trend of realisation of SC optimisation therefore auto manufacturers in India and all tiers of the SC have enormous opportunities to augment their entire supply chain process with the successful execution of SCM solution. By exploring Indian automobile sector, it has been found that uncertainties like demand and lead-time have undeviating impact on managing inventories and managers are facing great difficulties while controlling these parameters. Customer pleasure and cost reduction are again the key issues to be handled effectively and efficiently. Retailers in the supply chain face immense uncertainty regarding consumer demands and delivery lead-time.

To overcome these uncertainties and to manage inventory in a supply chain, in this work emergency lateral transshipments are allowed as alternative actions in order to reduce the cost of shortage or surplus inventory after demands are realized and we present a simple and intuitive model that enables to characterize optimal inventory and transshipment policy for  $n$  number of locations with  $\lambda$  products outfit by a single warehouse where stock is held to meet customers' demands. An analytical approach is urbanized for estimating the total expected costs (carrying, transshipments and lost sales) of the two policies i.e. with transshipment and without transshipment. This provides a mechanism for choosing between the two policies for any given set of

problem characteristics. ELT technique with variable costs (holding, stock-out and effective transshipment) has been used to overcome the uncertainties of demand and lead-time. Each retailer faces normally distributed random demand pattern, demand at every retail outlet is independent of other's demand. Lead-time is also normally dispersed and independent of other retailer's lead-time. All retailers are following episodic review policy. Based on this model an in-house program has been formulated in C++. Three case studies have been conducted on automobile manufacturing companies in India. Data has been unruffled in terms of day wise demand faced by the retailers, daily opening stock and cost coupled in holding inventory, stock-outs and transshipment from central warehouse and amongst retailers. The formulated program is being run on authentic data collected and the response has been compared with existing results. It has been observed that comparison indicators like stock-out quantities, surplus quantities and total associated cost have been decreased and it may also be concluded that lateral transshipment is an effective technique to strengthen the whole supply chain, to achieve better customer satisfaction and in terms of improving the service levels.

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## INTRODUCTION

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### 1.1 SUPPLY CHAIN

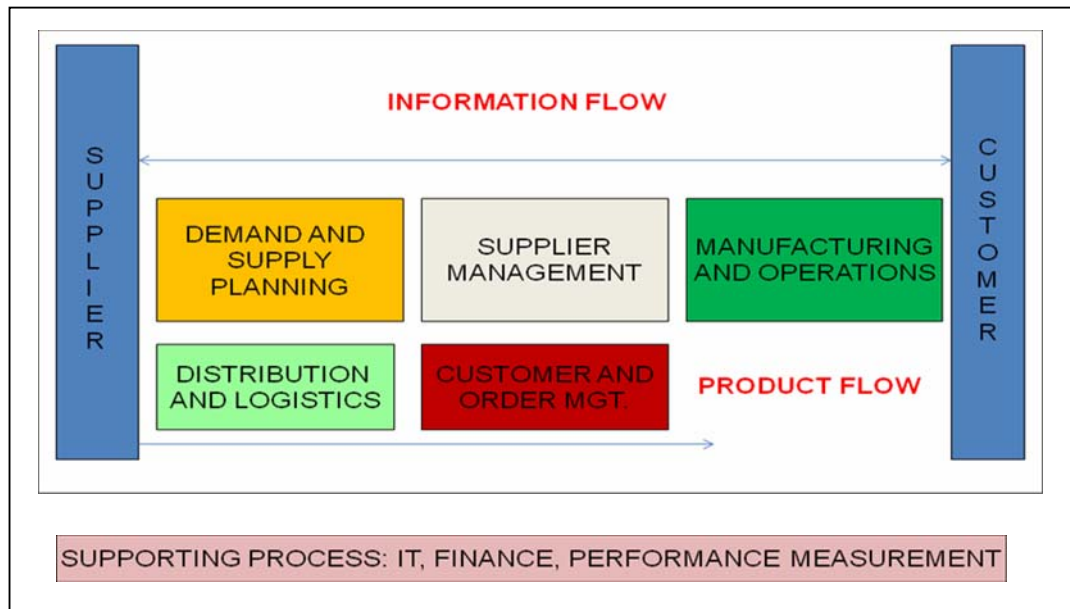
In this competitive era of 'LPG' i.e. Liberalization, Privatization and Globalization, modern marketing systems, introduction of products with short life cycles, and the discriminating expectations of customers have enforced business enterprises to invest in and focus attention on their Supply Chains (SCs) in order to meet out the level of customer's satisfaction and to survive in the competitive market (Ansari and Modarress, 1990, Sidola, 2004). Traditional functioning of marketing, distribution, planning, manufacturing, and the purchasing units of organizations along the supply chain were highly segregated and they used to function in an independent manner in order to meet out their own specific objectives which were often highly contradictory to the overall organizational goals. Many manufacturing operations are designed to maximize throughput and lower costs with modest considerations for the crash on inventory levels and distribution capabilities (Mason-Jones et al., 2000). Purchasing contracts are often negotiated with very little information beyond past buying patterns. The result of these factors is that there is not a single integrated plan for the organization rather there were as many tactics as businesses. Given that, there was an intense need for the emergence of some mechanism through which these different functions can be integrated together with the objective to function as a unified whole (Rhonda and Robert, 1999). Here comes the role of Supply Chain Management (SCM) strategies through which such amalgamation can be achieved and the past shortcomings of the system may be overcome.

The term supply chain management refers to cooperative management of materials and information flows between supply chain partners, to reach goals that cannot be achieved acting individually (Eric Sucky, 2005).

Supply chain as defined by The Council of Logistics Management is "*the process of planning, implementing and controlling the efficient, cost-effective flow of*

*raw materials, in-process inventory, finished goods and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements”.*

Supply chain management (SCM) is the combination of art and science that goes into improving the way your company finds the raw components it needs to make a product or service and deliver it to customers as shown in figure 1.1.



**Figure 1.1 Supply chain process.**

Supply chain management is a cross-function approach including managing the movement of raw materials into an organization, certain aspects of the internal processing of materials into finished goods, and the movement of finished goods out of the organization and toward the end-consumer. As organizations strive for focusing on core competencies and becoming more flexible, they reduce their ownership of raw material sources and distribution channels. These functions are increasingly being outsourced to other entities that can perform the activities in a better and cost effective way. The effect is to increase the number of organizations involved in satisfying customer demands, while reducing management control of daily logistics operations (Reiner and Trcka, 2004). Less control and more supply chain partners led to the creation of supply chain management concepts. The purpose of supply chain

management is to improve trust and collaboration among supply chain partners, thus improving inventory visibility and the velocity of inventory movement (Choi and Hong, 2002; Huang et al., 2003; Quinn, 1997).

### 1.1.1 Tribulations in a Supply Chain

The very concept of supply chain management has its own drawbacks to be addressed. The following problems are some of the burning issues:

- **Unjustified networking distribution:** Though this is a unified system yet it lacks deciding parameters related to number, location and network missions of suppliers, production facilities, distribution centers, warehouses, cross-docks and customers (Chu et al., 2000).
- **Distribution strategy:** In some specific cases supply chain management may not offer any ultimate solution to the questions related to operational control (centralized, decentralized or shared); delivery scheme, e.g., direct shipment, pool point shipping, cross docking, DSD (direct store delivery), closed loop shipping; mode of transportation, e.g., motor carrier, including truckload, parcel; railroad; intermodal transport. Issues related to ocean freight; airfreight; replenishment strategy (e.g., pull, push or hybrid); and transportation control (e.g., owner-operated, private carrier, common carrier, or contract carrier) are also to be explored for ensuring a safer business environment (Dave and Saxena, 2005).
- **Trade-offs impacts:** Ensuring well coordination in due process of all concerned activities to achieve the lowest total logistics cost is mandatory. Trade-offs may increase the total cost if only one of the activities is optimized e.g. full truckload (FTL) rates are more economical on a cost per pallet basis than less than truckload (LTL) shipments. If, however, a full truckload of a product is ordered to reduce transportation costs, there will be an increase in inventory holding costs which may increase total logistics costs and therefore it is imperative to take a systems approach when planning logistical activities.

These trades-offs are key to developing the most efficient and effective Logistics and SCM strategy (Ballou, 1992).

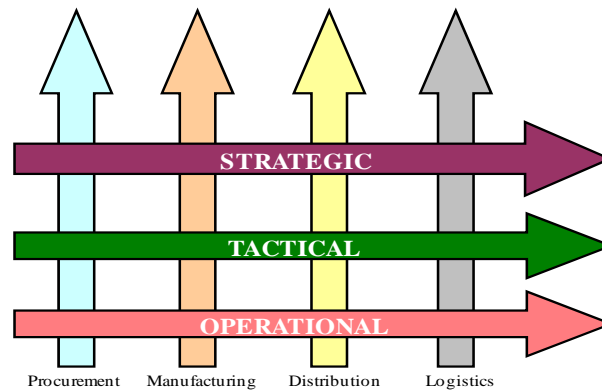
- **Information:** Process integration through the supply chain to share valuable information, including demand signals, forecasts, inventory, transportation, potential collaboration, etc. is another major concern (Ansari and Modarress, 1990; Childerhouse and Towill, 2002; Huang et al., 2003; Rich and Hines, 1997).
- **Managing inventory:** Issues related to quality, quantity and locations of inventory, including raw materials, work-in-progress (WIP) and finished goods and ensuring an effective working inventory in unforeseen circumstances are yet to be managed (Clark, 1972).
- **Cash-flow:** Managing the payment and its mode, terms and methodologies for exchanging funds across entities within the supply chain are other functional hurdles to be encountered.

Supply chain execution means managing and coordinating the movement of materials, information and funds across the supply chain. The flow is bi-directional i.e. from supplier to customer and vice versa (Cho and Gerchak, 2005).

### 1.1.2 Key Decisions

In order to ensure smooth functioning of the process of supply chain the decisions may further be classified into three major segments – strategic, tactical and operational (Biswas and Narahari, 2004) as shown in figure 1.2 below. Strategic decisions are long run policy decisions which are to be made typically over a longer time horizon and guide supply chain policies from a design perspective whereas the tactical decisions are of intermediate time horizon, as they cover the terms that require regular planning and control over medium span of time. Finally, on the other hand there are certain decisions which are to be taken as the part and parcel of routine activities and such decisions are termed as operational decisions. They are short term,

and focus on activities over a day-to-day basis targeting to manage effectively and efficiently the product flow in the “strategically” planned supply chain.



**Figure 1.2 Supply chain decisions.**

The mindset of professionals working for the establishment of an effective and smooth functioning SC needs to be reconditioned as per the recent emerging requirements; it should be adopted as ‘an innovative way of strategic thinking’- not the ‘techniques’ and also should be a deep rooted ‘ethical corporate culture’ not the latest of ‘management tool’ (Wang et al., 2004).

### **1.1.3 Performance Measurement**

Performance measurement is defined as the process of quantifying the effectiveness and efficiency of action (Chan, 2003). No measurement system can claim that it is full proof and ultimate and so whatever is measured has potential to improve. Earlier the performance measurement management in the supply chain was focused mostly on quality of production system and in operations and there are sufficient tangible processes that can be precisely measured and monitored (Gunasekaran et al., 2004). In the modern economy, companies are not the mass production driven. Knowledge-oriented production is an emerging stimulus for the organizations which are competing in twenty first century and in the environment of competitiveness companies are focusing more on intangible processes in the supply chain functions. Instead of individual metrics in measuring supply chain performances

corporate are attentive to develop overall performance measurement system (Stewart, 1995).

Supply chain objectives are often conflicting e.g. excellence in services cost money. Before developing any supply chain performance measurement system the developer must set metrics considering the balance of below mentioned factors:

- Performance measurement related to uncertainties affecting inventories, and maintaining a balance amongst them for managing a working inventory.
- Performance measurement in innovation and in continuous improvement.
- Metrics for financial and non-financial parameters.
- Customer oriented and introspection metrics.
- Intra and inter organizational information setup.
- Measurement related to delivery lead-time, process cycle time, supply chain response time.

Recently, number of firms realized the potentials of SCM in routine and small scale operations management but very often they lack the insight and visionary transparency for the development of effective performance measures and metrics needed to achieve a fully integrated SCM (De Toni and Tonchia, 2001). In order to meet effective performance measurement goals it is advisable to opt a balanced metrics that supports the overall scenario as the bench mark companies are using.

#### **1.1.4 Supply-chain strategies for spearheading competitiveness**

The most important perspective of modern business management is that individual businesses no longer compete as only autonomous entities, but rather within supply chains (Lambert and Cooper, 2000). In this emerging competitive environment of the twenty first century, the ultimate success of the business will depend on management's ability to integrate the company's intricate network of business relationships.

Emergence of new technologies and the ever-increasing intensity of competition are forcing organizations, firms and industries to reexamine how they do business, meet new customer-driven challenges, companies are re-thinking, re-structuring and re-investing their supply chains in order to survive, succeed, excel and even in some specific cases targeting to spearheading competitiveness (Drucker, 1998). For example in case of any mismatch existing between what the supply chain may offer with respect to customer demands, the company can either alter the structure of the supply-chain design or alter its strategies. Adaptation of effective strategies of an efficient supply chain management can help any firm or industry in enhancing competitiveness level as the firm's competitive strategy defines the set of customer demands that it seeks to satisfy through its products and services (Lambert and Cooper, 2000). The ultimate objective of SCM is to achieve a 'strategic fit' between the company's competitive strategy and supply-chain strategy. Supply-chain strategies are helpful in determining the nature of procurement of raw materials, transportation of materials to and from the company, manufacture of the product or operation to provide the service and distribution of the product to the customer, along with follow-up services (Injazz and Antony, 2004). The regulatory factors that can stimulate competitiveness of any firm if they are effectively taken care of during the due process of supply chain are:

- Decision phases
- Performance
- Drivers and obstacles
- Network Designing
- Managing & planning inventories
- Managing uncertainties
- Sourcing, transporting and pricing products
- Coordination and technology

Nowadays, a considerable number of companies like Maruti Udyog Ltd., Mahindra and Mahindra, Dell and HP etc. are implementing supply chain management practices. Many of them are striving hard for spearheading competitiveness in their respective sphere through cross-functional collaboration, both

within the enterprise and supply chain partners. But very few companies have successfully implemented the practices and technologies needed to do it well. The use of different practices is highly connected with the level of supply chain process development as well as the level of integration of these processes for ensuring competitive advantages. With the globalization of the world economy, the diversity and environmental factors that influence a company's glocal (both global as well as local) strategies and approach, supply-chain drivers influencing the companies to become increasingly competent so that they can justify their dominance and maintain their dynamic growth. Different approaches to meet out the newly emerging demands of competitiveness require different degrees of supply-chain integration, as well as different supply-chain strategies and structures. By ensuring a full proof SCM firms and industries can enhance their capabilities to spearheading competitiveness.

#### **1.1.5 Dynamics of Relationships in a Supply Chain**

Supply chain constitutes of many players, each of the constituents play their specific roles in converting raw materials into finished goods to meet customer requirements. The success of the supply chain is directly proportionate to the type of relationship that exists among these players who are accountable for the management of the overall process of supplying raw materials from the suppliers to different levels of customers until the product reaches in the hands of the end user in its finished form (Sahay, 2003). Different echelons in a supply chain are suppliers, manufacturers, distributors, retailers or supermarkets and end customers regardless of the sort of products being introduced or produced. To conclude it may be inferred that SCM principles recommend close association among all supply chain key performers (Ryu et al., 2009).

In twenty first century era where organizations enter into the new business environment which deals with the idea of maximizing efficiencies, they face significant business risks associated with the increased dependence on business partners to shorten cycle times and deliver materials and supplies on increasingly shorter notice. High level competitiveness and ensuring major share of benefits to

their own departments and units, stakeholders compete among each other and this generates an atmosphere of distrust and wariness among players in the supply chain (Zelbst et al., 2009). Hence this unhealthy supply chain relationship that exists usually falls in between arms lengths negotiation to full collaboration or integration. Other such development is the power considerations which were exerted by certain players in a supply chain. This type of relationship is especially prevalent in the automobile industry.

Successful supply chain management requires cross-functional integration within the firm and across the network of firms that comprise the supply chain ( Sidola, 2004, Chandra and Kumar, 2001). In order to ensure smooth functioning among all the stake holders the process of automating connections with trading partners, organizations are increasingly dependent on upstream and downstream business partners and here technology plays a pivotal role in not only making things transparent but in maintaining relationships in the environment of faith and integrity. For the establishment of an ideal professional environment organizations should focus on supply chain relationship management (SCRM) and the improvements in performance that result from better management of key relationships. In some benchmarked companies executives struggle to achieve the necessary integration so that they may work in congenial environment by understanding the supply chain management processes and create more integrated supply chains which will lead to higher revenues and increased profitability for all member firms.

The level of success of The Glocal (Global as well as local) Supply Chain Management depends on developing close relationships among all intra organizational and inter organizational players viz. suppliers, manufacturers, distributors, retailers and customers so it may be safely inferred that supply chain management is relationship management. An effectively and strongly inbuilt relationship is a mandatory tool that can be used to minimize and control uncertainties that affect supply chain management and structure, restructure the supply chain functioning even in the reverse and unforeseen situations. The identified key relationships while implementing the SCM are the partnership model or lateral transshipment technique which is a tailored business relationship based on mutual trust, openness, shared risk and shared rewards that results in business performance

greater than would be achieved by the two firms working together in the absence of partnership and so there is an urgent need to explore the impact of such relationship profiles or relationship structures on supply chain performance (Lee et al., 2007).

## **1.2 INVENTORY: A CORNERSTONE IN SUPPLY CHAIN**

The level of customers' satisfaction directly depends on the flexibility level of the supply chain. Flexibility itself is often imperfect and questionable if the lead-time is prolonged, uncertainties are not minutely speculated as well as not effectively managed, and mismanagement of unforeseen event (Guillen et al., 2005). To counterbalance this lack of flexibility companies will keep inventories at various levels of the supply chain. Inventory management is primarily about specifying the size and placement of stocked goods. Inventory management is required at different locations within a facility or within multiple locations of a supply network to protect the regular and planned course of production against the random disturbance of running out of materials or goods. The scope of inventory management also concerns the fine lines between replenishment lead-time, carrying costs of inventory, asset management, inventory forecasting, inventory valuation, inventory visibility, future inventory price forecasting, physical inventory, available physical space for inventory, quality management, replenishment, returns and defective goods and demand forecasting. The most significantly affecting factor of supply chain is the inventory plans which are to be structured in such a way that they accommodate variability in demand, lead-time and other uncertainties especially when the company is dealing with multiple and varying products (Musalem and Dekker, 2005). Inventory management starts right from the very beginning of procurement of quality materials for manufacturing, and then leading to its effective processing until it reaches in the hands of customers in the form of finished products.

Inventory management in SCM doesn't restricts only to the management of lead-time, procurement of materials for production, effective processing, and unforeseen situations' speculations and their effective spatial and chronological management, rather it also covers the effective and careful handling of stocked up finished goods, utilizing the unprocessed materials and even processing and recycling

the scraps and so it becomes pivotal to frame an overall plan that considers all materials to be stocked up throughout the supply chain (Eric Sucky, 2005). The inventory quandary applies to all inventories-finished goods, raw materials, parts and components, and work-in-process. It includes new products and existing products. It covers all types of businesses-manufacturers, distributors, wholesalers, retailers and others in about every industry (Kalchschmidt et al., 2003).

The purpose of supply chain management is to drive out inefficiencies, especially excess inventory. Yet, inventory is a buffer against uncertainty. Uncertainty is difficult to forecast. In supply chain management (SCM), the inventory control problem is very complicated and challenging because the planner needs to consider several factors, for example, supply chain structures, coordination levels, and information sharing processes (Axsäter, 2005). In modeling a company's success or failure inventory control is the major decisive factor which has a great impact on the company's ability to manufacture goods for sale or to deliver up to customers' satisfaction on orders of finished products and will balance the customer's need to secure products quickly with the business need to minimize and regulate inventory costs. The inventory control policy used by each entity is also an important factor because it affects the inventory replenishment process of the upstream entity. The upstream demand may be distorted and far from the actual demand faced by the downstream entity. This phenomenon is known as the Bullwhip Effect (Dejonckheere et al., 2004). Many classical inventory control systems (s, Q, s, S, R,S, R,Q, and R,s, S, etc. where s, Q, S, and R denote reorder points, reorder quantities, order-up-to levels, and periodic review periods, respectively) are still used in the supply chain environment. However, determination of their control parameters is very difficult. For SCM, all entities in the supply chain should be planned and controlled simultaneously to obtain good control parameters and low inventory costs (Christopher and Gattorna, 2005).

In today's complex marketplace, the competition is between supply chains rather in individual companies. A primary consideration of supply chain management (SCM) is the flow of goods from the source of raw materials to the ultimate end consumer. Inventory management is one of the cornerstones of SCM and inventory is

a key cost-contributor in any supply chain (SC). In accounting inventory is considered an asset.

### **1.2.1 Inventory Costs**

To control the amount of revenue invested in the establishment of a highly efficient inventory is also one of the major objectives of SCM. There are three main types of costs involved to carry standard inventories and safety stocks i.e. ordering and setup cost, holding cost and stock out cost. A good inventory control system will balance carrying cost against shortfall cost. In the inventory analysis relevant costs are considered

#### **Order/setup Cost**

- Expense of issuing a purchase order to an outside supplier or from internal production setup costs
- Vary directly with number of orders or setups
- Order cost includes transportation cost, and cost for requisition, analyzing vendors, writing purchase orders, transportation cost to transport the order quantity, receiving materials, inspecting materials, following up orders and doing the process necessary to complete the transaction.

#### **Holding cost or carrying Cost**

- Cost associated with investing in inventory and maintaining the physical investment in storage
- Contains capital costs, taxes, insurance, handling, storage, shrinkage, obsolescence, and deterioration

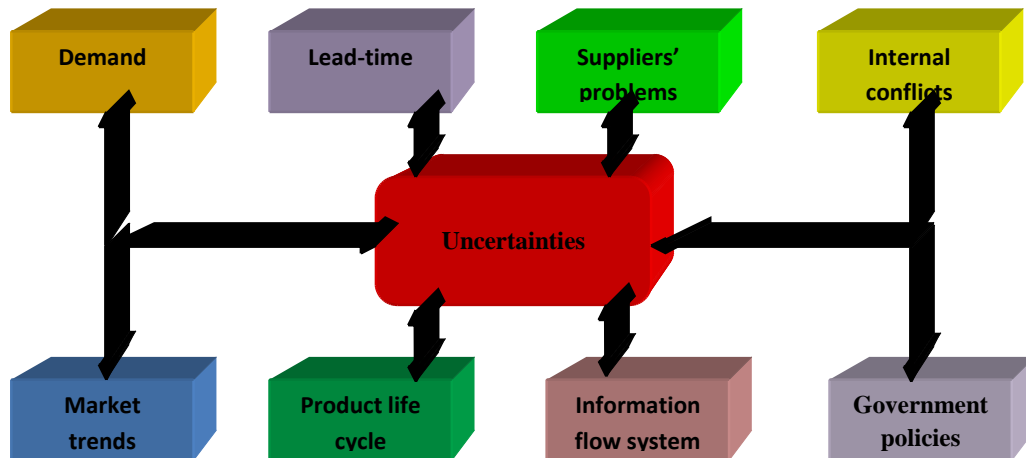
#### **Stock-out costs**

- Economic consequence of an external or an internal shortage
- External shortage – when customer's order is not filled

- Internal Shortage – When an order of a group or department is not filled
- External shortages can incur stock-out cost, present profit loss and future profit loss
- Internal shortage can result in lost production and delay in completion date

### 1.2.2 Factors (Uncertainties) affecting Inventory Control

One of the major issues in a supply chain is ensuring hassle free and suave functioning of inventory and so the role of inventory as a cushion against uncertainties and unforeseen oddities has been established for a long time (Gupta and Maranas, 2003). Towards the end of twentieth century, the disadvantages of holding huge inventories have been increasingly identified, particularly because of its adverse impacts on supply chain and on collaborative responsiveness. Figure 1.3 represents the uncertainties that affect the inventory control policies.



**Figure 1.3 Uncertainties affecting inventory control.**

To reduce the impact of these inventory uncertainties, supply chain managers must first understand their sources, the targeted market size, researched feasibility outcomes and the magnitude of their impact. Surprisingly many supply chains do not document and track these variables which may result into over-stock or under-stock, miscalculation of the lead-time and invest in the wrong resources for performance

improvement (Tsiakis et al. 2001). Due to demand variables, inventory investments can be very high in supply chain systems. There are three general approaches available to manage inventory i.e. inventory control approach, flow management and following inventory models.

A derived or dependent demand arises from the production of another product which means that the demand for an item is related directly to the demand for some other product. The item may be a component, raw material or subassembly. It should be clearly assimilated that demand for a company's end product may often be anticipated but the demand for raw materials and components parts cannot be forecasted but to be calculated. For example, after some feasibility calculations when John Deere came to the inference of the demand for a tractor, it can simply compute the demands for the parts, materials, and components needed to produce that tractor. Different manufacturing segments of all sizes use such calculations which are part of flow management to manage inventories, schedule deliveries for inputs, and manage capacity. Flow management software has evolved from Materials Requirements Planning (MRP) in the 1960s to the much more complex Enterprise Resource Planning (ERP) of the 1990s. A flow management system is set in motion by the demand for end products.

Independent demand arises from demand for an end product. End products are found throughout a supply chain e.g. wheat is an end product for a grain elevator, as is flour for a miller or cereal for a grocer. An independent demand is uncertain, meaning that extra units or safety stock must be carried to guard against stock-outs at the same time on the other hand there always remains a risk of low demand resulting into surplus inventory. Supply chain coordination can decrease the uncertainty of intermediate product demand, thereby reducing inventory costs (Cohen et al. 1986).

Independent demand's structure and requirements of logistics may vary as per the stages in the products' life cycle (introduction, growth, maturity, saturation and decline) strategy which normally involves getting to profitability, quickly recovering startup costs, then sustaining highly optimized profitability for as long as possible, and finally acting decisively for products in decline to minimize risks of losses. Understanding products life cycle can help organizations in opting logistical tactics,

inventory levels and supply chain designs. The final objective for companies should be to have just enough inventories to satisfy consumer demand. Another life cycle attribute is that demand uncertainty shifts as the time progresses from the introduction to other advanced stages, relative stability during maturity, and increasing uncertainty in decline. This uncertainty drives forecasting accuracy and the level of safety stock required to meet customer service expectations (Petrovic et al., 1998).

More focus should be given on the accuracy of the forecasting demand for ensuring a prolonged longevity of maturity stage which will enhance the chances of profitability. The twenty first century competitive marketing makes it really difficult for many companies to forecast sales because of product proliferation. The intensive extensions in products line result in more products that cannibalize sales and reduce the life cycle even before the product is introduced in the market in some of the cases.

Inventory levels are affected by customer service expectations, demand and lead-time uncertainty, and the flexibility of the supply chain. For products with relatively certain demand and a long product life, it should be relatively easy to maintain desirable customer service standards even as inventories are reduced. However, for products characterized by erratic demand, a short life cycle, or product proliferation, a more responsive supply chain and larger buffer inventories may be needed to meet a desired customer service level.

Consumers are demanding more service from firms throughout the supply chain. Firms with high customer service levels may gain a competitive advantage over those that do not have the supply chain capabilities in place or the ability to manage them. Firms who understand their demand recognize stock-out costs and carry appropriate levels of inventory are ultimately better able to effectively manage inventory and provide the desired service level to customers.

In the last couple of decades, the number of products offered to the market has generally exploded. At the same time, the product life-time has decreased drastically. The combination of these two trends leads to increased inaccuracy of the demand forecasts, leading to firms facing an increased demand and lead-time uncertainty.

### **1.2.3 Inventory Classifications Schemes**

Depending upon the nature and size of the industry, there are items ranging from the smallest to the largest in terms of value, size, complexity and criticality which are not even feasible to manage or exercise strict control. In the absence of a disciplined classification of control it will only be a wasted effort with too little benefit to manage the assets, henceforth the principle of management by exception is to be applied mandatorily. For this purpose the items should be classified based upon a certain criteria to facilitate selective control. Such control minimizes waste of efforts as well as confusions. The various ways in which inventory may be classified are (Narain and Subramanian, 2009):

- ABC {Annual consumption value ‘Vital few, trivial many’: Class A, class B and class C items} analysis
- XYZ {Stock value: Very high X, Medium Y, Least Z} analysis
- VED {Relative importance in production system: Vital items, Essential items, Desirable items} analysis
- FSN {Pattern of issue from the store: Fast moving, Slow moving, Non-moving} analysis
- PQR {Based on shelf life requirements: Frequent attention P, Medium attention Q, Least attention R} classification
- SDE {Ease of obtaining: Scarce, Difficult, Easy} classification
- GOLF {Nature of source: Government, Open market, Local sources, Foreign sources} classification
- SOS {Time of availability: Seasonal, Off-seasonal} classification
- HML {Unit price of material: High, Medium, Low} classification

### **1.3 LATERAL TRANSSHIPMENT: A RISK REDUCING TOOL**

Supply chain (SC), which involves the configuration, coordination, and improvement of sequentially related set of operations in establishments, integrates technology and human resource capacity for optimal management of operations to

reduce inventory requirements and provide support to enterprises in pursuance of a competitive advantage in the marketplace. A coordinated SC integrates procurement, production, and distribution and links together suppliers, manufacturers, distributors, customers and carriers in a network system that allows for effective planning, information exchange, transaction execution, and performance reporting (Cooper et al., 1997; Ellarm and Cooper, 1990).

Supply chain management involves the movement of products, services, and information between and within businesses, the creation of value, and support of enterprises in the pursuance of a competitive advantage in the market place. It involves the cooperation and coordination of activities of all parties for the production and distribution of products to the final consumer with mechanism in place to optimize inventories across the entire supply chain. With effective management of products to create added value and competition among firms move from national to regional and to a global level, new strategies are being adopted by a number of manufacturers and retailers, particularly, in the manufacturing industries to gain a competitive advantage in world markets. Pressures from low-cost and the new global competitive environment require companies to be more productive, react faster to market changes, and maintain smaller inventories (Burton and Banerjee, 2005). These developments in the operation of businesses entail significant changes in the traditional ways of manufacturing system.

The upstream and downstream coordination engendered by supply chain management with the goal of minimizing uncertainty and variations along the supply chain shows that businesses can no longer expect that the objective of business can be met just by becoming efficient in itself. The situation requires that for value to reach the customers, efficiency must be evident even in the suppliers, the distribution channel, and all associated activities and partners. Competition is no longer between individual businesses, but between groups of companies that are linked together in a chain for delivering customer value.

The collaborative concept of joint competitiveness in the globalised era is much more appealing than going alone in any professional venture. The relationships among organizations are to be tested with the escalating demand of supply chains. In

a competitive and collaborative supply chain, a number of risks exist that must be managed among the participants. Risks of unforeseen demands, lead-time, market trends, product life cycles, internal conflicts and even government policies etc. are to be compensated and managed effectively in order to ensure the customers' satisfaction e.g. suppose many retailers are selling identical products but at the time of shortage they share their product to each other. By doing so they not only overcome the uncertainties but at the same time they also minimize the risks as the transshipment costs generally remain lower than both the shortage cost and the cost of an emergency delivery from the central warehouse in the situations where transshipment time is shorter than the regular replenishment lead-time. Thus mutual collaboration mostly takes the form of lateral inventory transshipment from an outlet with a surplus of on-hand inventory to an outlet that faces a stock out (Krishnan and Rao, 1965). Professional adoption of lateral transshipment simultaneously reduces the total system cost and ensures the better services at the retailers' outlets in meeting out the best possible level of customers' satisfaction. These service levels cover the satisfied demand or the periods during which the products were delivered to the customers. The stocking locations that share their inventory in this manner are said to form a pooling group, since they effectively pool their resources to reduce the risk of shortages and provide better service at lower cost (Herer et al., 2002). A commonly used strategy to introduce flexibility in the system is to establish transshipment links between locations at the same echelon. This means that locations at the same echelon in some sense share inventory. Lateral transshipments (also referred to as inventory pooling) represent an effective strategy to improve a company's system availability while reducing the total system costs. Lateral transshipments are used to satisfy a demand at a location that is out of stock from another location with a surplus of on-hand inventory (Fredrik Olsson, 2008).

Since costs for lateral transshipments are generally much lower than downtime costs, lateral transshipments can reduce total system costs. By allowing transshipments among locations better customer service can be achieved with retained inventory levels. Overall performance of the supply chain is enhanced by improving the service levels (Sidola, 2004). These are, demand service level and period service level. Demand service level provides better idea of contented customers. But when

previous day's unsatisfied customer demand, does not influence next day's demand, then Period service level can be used to measure the performance of the system.

It should also be emphasized that with modern information technology, strategies such as lateral transshipments are indeed possible to implement in practice.

### **1.3.1 Need for Transshipment**

- It introduces flexibility in the system means that locations at the same echelon in some sense share inventory.
- By allowing transshipments among locations better customer service can be achieved.
- Reduced inventory levels.
- Minimize costs.
- Increase profits.
- Reduced managerial implications.

### **Emergency Lateral Transshipment (ELT)**

- ELT mandates emergency redistribution from a retailer with ample stock to a retailer that has reached a stock out.

### **Preventive Lateral Transshipment (PLT)**

- PLT reduces this risk by redistributing stock to prevent a stock out at a retailer before demand exceeds the inventory level.

ELT responds to actual stock-outs while PLT reduces the risk of possible future stock-outs. Several inter-organizational dynamics come into play when addressing information sharing across the supply chain. Two issues in particular are risk and power. All enterprises participating in a supply chain management project accept a specific role to perform. They also share the joint belief that they and all the

other supply chain participants will be better off because of this collaborative effort. Each member specializes in the function or area that best aligns with its distinctive competencies. Risk occurs in that rather than prospering or failing on the basis of its own efforts. Each firm must now rely on other supply chain members, as well as in its own efforts in determining the success of the supply chain. Some supply chain members are more dependent than other for the supply chain success. Thus, members with the most at stake may take more active roles and assume greater responsibility for fostering cooperation, including the information sharing efforts, throughout the supply chain. Although not universal to all industries, there has been a general shift of power from manufacturers to retailers over the last two decades, which has resulted from a combination of factors. One is the trend toward consolidation at the retail level within the supply chain. Perhaps more importantly, retailers sit in a very important position in terms of information access for the supply chain. For several reasons major retailers have risen to this position of prominence with transshipment technologies such as i) bar codes and scanners, ii) their sheer size and sales volume and most prominently, iii) their position within the supply chain right next to the final consumer. This combination of factors has put retailers in a very powerful position within the supply chain.

Consider for instance the case when a retailer has no stock on hand when a demand occurs, then, instead of replenishing stock from the central warehouse with relatively long lead-time, transshipment from another installation is realized to meet this demand and thus obtain better service. These sorts of transshipments are often termed as emergency transshipments, since the call for the transshipment originated from a shortage. Instead of making transshipments when an installation faces a shortage or has no stock on hand, transshipments can be made routinely as a balancing act in order to reduce the system cost. This type of transshipment policy has often been applied in periodic review models.

#### **1.4 SUPPLY CHAIN SCENARIO IN INDIAN AUTO SECTOR**

The distribution system for new automobiles has remained unchanged for many years, with more emphasis on supplying customers from stock held at retailers. Despite high stocks, the performance of the supply chain has failed to meet customer

expectations in terms of delivering the exact specification desired within an acceptable timescale. Today Indian automotive industry is completely capable of producing various kinds of vehicles and can be divided into three broad categories: two-wheelers, cars and heavy vehicles. Vast scope exists for Indian automobile and auto component manufacturers to reduce their logistics costs with the implementation of SCM solutions. As India is a developing country, and fascinatingly, there has been an upward trend of realisation of supply chain optimisation. SCM solution market has been making inroads in India and it is being established widely by many automobile industries in the country, particularly manufacturing ones where inventory carrying cost is very high. Several automobile manufacturers in India have taken positive actions to manage their logistics cost and get better customer services and measures have been undertaken by Indian companies to develop their supply chain (Kamala and Doreswamy, 2007).

Auto manufacturers in India and all tiers of the supply chain have immense opportunities to enhance their entire supply chain process with the successful implementation of SCM solution. At present there are 15 manufacturers of passenger cars & multi utility vehicles, 9 manufacturers of commercial vehicles, 16 of 2/3 wheelers and 14 of tractors besides 5 manufacturers of engines. Total turnover of the Indian automobile industry is expected to grow from USD 34 Billion in 2006 to USD 122 Billion in 2016 (Ministry of heavy industries and public enterprises Government of India, 2006). The automotive industry is today a key sector of the Indian economy and a major foreign exchange earner for the country.

Today, India is the 2<sup>nd</sup> largest tractor and 5<sup>th</sup> largest commercial vehicle manufacturer in the world. Hero Honda with 3.9 million motorcycles a year is now the largest motorcycle manufacturer in the world. With the growth of transportation system the automotive industry of India is also growing at rapid speed, occupying a vital place on the 'canvas' of Indian economy. By exploring Indian automobile sector, it has been found that uncertainties like demand and lead-time have direct impact on managing inventories and managers are facing great difficulties while controlling these parameters (Srinivas and Shekhar, 1997). Customer satisfaction and cost

reduction are again the key issues to be handled effectively and efficiently (Singh et al., 2007).

## **1.5 SCOPE OF THE WORK**

As the products offered to customers have emerged out enormously bearing short span of their demand in relative markets, leading increased inaccuracy of the demand forecasts and lead-time uncertainties. Therefore controlling these uncertainties in a supply chain is a key issue for managing inventories. In a supply chain structure, all the individuals are bearing risks that must somehow be managed efficiently. Earlier the co-operation along the supply chain was taken care of but in this work the cooperation factor has been carried out across the supply chain. Emergency lateral transshipment practice with variable holding, stock-out and effective transshipment costs has been used to overcome the uncertainties of demand and lead-time. The automotive manufacturing industry is an extremely competitive one and many automobile players are focusing on their supply chains in global perspectives for sources of competitive advantage. The distribution system for new automobiles has remained unchanged for many years, with more emphasis on supplying customers from stock held at retailers. Despite high stocks, the performance of the supply chain has failed to meet customer expectations in terms of delivering the exact specification desired within an acceptable timescale. Indian automobile and auto components industry is on a roll and there is a vast scope for the management for enhancing the lateral transshipment approach in controlling the uncertainties of inventory control in the adopted supply chain.

As the retailers are apart by moderate distances so lateral transshipment approach may be implemented amongst them and even no additional transportation facility is required rather transshipment is done by road and by the vehicle itself. It is observed that emergency lateral transshipment is an effective technique to strengthen the whole supply chain, to achieve better customer satisfaction, reduces inventory and associated costs and improves the service levels and it has attained prominent place in controlling these parameters.

## 1.6 ORGANIZATION OF THE THESIS

In the forthcoming sections the supporting text related to the descriptions of literature reviewed, analytical approach, example problems, different case studies and conclusion drawn etc. are organized as follows:

**Chapter 2** presents the review of the published literature on historical development of supply chain, role of inventory, uncertainties affecting supply chain performance, lateral transshipment that covers the relationship amongst supply chain members and scenario of supply chain in automobile sector at International and at National level. Also, the identified gaps in the literature have been discussed.

**Chapter 3** deals with the problem formulation and adopted methodology that covers the problem statement, model formulation and assumptions used in the model. Based on this model a program has been formulated in C++. An example problem has been taken for the verification and evaluation of the model developed.

**Chapter 4, 5 and 6** provide the three case studies based on Indian auto industries (Maruti Suzuki India Limited, Baja Auto Limited and Hero Honda Motors Limited) respectively. Further parameters like companies' profile and data collection have been given. Collected data has been run on the developed program and the outcomes in terms of reduced inventory, associated costs and improvement in service levels have been compared with the existing results of the companies. Respective results for the three case studies are also explored and explained in these chapters.

**Chapter 7** gives the epitome of the present work carried out and at the end of this chapter some scope for future work on the related topics has been enumerated.

### LITERATURE REVIEW

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#### 2.1 HISTORICAL DEVELOPMENT OF SUPPLY CHAIN MANAGEMENT

Discussing the profile of the future, Forrester (1958) projected that after a period of research and development involving fundamental analytic technique, *'There will come general recognition of the advantage enjoyed by the pioneering management who have been the first to improve their understanding of the interrelationship between separate company functions and between the company and its markets, its industry and the national economy'*. Though his critique is more than fifty years old, it appears that Forrester acknowledged key management issues and illustrated the dynamics of factors allied with the phenomenon referred to in contemporary business literature as supply chain management (SCM). For example, at the 1995 Annual Conference of the Council of Logistics management, 13.5% of the concurrent session titles contained the words "supply chain". At the 1997 conference, just two years afterward, the number of sessions containing the expression rose to 22.4%. Moreover the term is recurrently used to describe executive responsibilities in corporations (La Londe and Bernard, 1997). SCM has become such a hot matter that it is difficult to pick up a periodical on manufacturing, distribution, marketing, customer management or transportation without seeing an article about SCM (Ross, 1998).

In the struggle for marketplace advantage, organizations, consultants, practitioners and academicians have attempted to organize and incorporate supply chain management (SCM) concepts and practices into their business processes. SCM involves challenges such as developing faith and teamwork among supply chain partners, identifying best practices that can facilitate supply chain process configuration, integration and successfully implementing the latest collaborative information systems and internet technologies that coerce efficiencies, performance, and quality throughout the supply chain (SC). Organizations distinguish that along with the added variety and responsiveness squeeze, they must remain malleable to

future changes. Supply chain management (SCM), highlights the need and advantages of abandoning the companies' barriers that severely separate the entities involved in a partnership, and extending integration ahead of the borders of a single company (Ellram, 1990; Rhonda and Robert, 1999). Many organizations today are forced to augment their global market share in order to stay alive and maintain growth objectives. At the same time, these same organizations must shield their domestic market share from international competitors. The challenge is how to inflate the global logistics and distribution network, in order to ship products to customers who demand them in a vibrant and rapidly changing set of channels. Strategic positioning of inventories is vital, so that the products are available when the customer wants those (Handfield et al., 2002).

Supply chain management offers an integrated philosophy for managing organizations' purchasing and distribution processes based on souk perspectives. The overall objective of SCM is to contribute to improvements in the company's bottom line or prosperity. Related objectives comprise reducing the costs mainly by reducing the inventory levels and increasing the revenues by improving customer service through synchronization and integration along the material flow, win-win relationships and end customer focus. To contend successfully, organizations are embracing supply chain management because it focuses on events along the entire value chain (Bechtel and Jayaram, 1997; Childerhouse et al., 2002; Tan, 2001; Vonderembse, 2002). SCM integrates suppliers, manufacturers, distributors, and customers through the use of information technology to meet customer expectations efficiently and effectively (Ansari and Modarress, 1990; Childerhouse and Towill, 2002; Choi and Hong, 2002; Huang et al., 2003; Quinn, 1997; Rich and Hines, 1997; Thomas and Griffin, 1996). The supply chain viewpoint is predicated on the fact that competition is shifting from firm versus firm to supply chain versus supply chain, and SCM is the loom to designing, organizing, and executing these actions. As a result, groups of companies can react quickly and in a unified manner with high-quality, differentiated products demanded by finicky final consumers while achieving system-wide advantages in cost, time, and quality (Carter, 1996; Davis, 1993; Hewitt, 1994; Mabert and Venkataramanan, 1998; Persson and Olhager, 2002; Vonderembse, 2002). The supply chain consists of all stages involved, directly or indirectly, in fulfilling a

purchaser demand. Within each association, such as manufacturer, the supply chain includes all functions concerned in fulfilling customers' request. These functions include fresh product development, marketing, operations, allocation, finance, and purchaser service etc. Supply chain involves the executive of flows between and within stages to maximize total profit (Chopra, 2001). Fisher's (1997) supply chain classification format pointed out the potential negative consequences of a variance between a supply chain and its products. A chain designed for slightest cost operations may be too inflexible to handle products that require a swift market response to satisfy variable market demands. Stock-outs and lost sales will result from that inflexibility. Similarly, a supply chain that is designed for elastic and rapid response is unnecessary and probably too exclusive for standardized products with stable demands. Second, it must overcome the well-documented bullwhip effect (Senge, 1990; Lee et al., 1997). The bullwhip effect is a behavioral observable fact in which orders become distorted and exaggerated as the members of the chain, fearful of limited supply or imminent demand increases, over-order to make certain they receive sufficient supplies. Controls are needed to moisten the bullwhip effect as much as possible.

“Management is on the edge of a major breakthrough in understanding how industrial company conquest depends on the interactions between the flows of information, materials, money, manpower and capital equipment. The way these five flow systems interlock to intensify one another and to cause change and fluctuation will form the foundation for anticipating the effects of decisions, policies, organizational forma and investment choices”. A theory of distribution management was introduced that recognized the integrated nature of organizational relationships (Forrester, 1958). The entanglement of the organizations envisaged the argument that system dynamics can manipulate the performance of functions such as research, engineering, sales and promotion. This fact was illustrated utilizing a computer simulation of order information flow and its influence on production and distribution recital for each supply chain member, as well as intact supply chain system. Imitation of this phenomenon includes the “Beer Game” simulation and research covering the “Bullwhip Effect” (Lee et al., 1997).

As competition shifts from a company orientation to a supply chain orientation, SCM is touted as a policy of choice for unbeaten competitors (Quinn, 1997; Rich and Hines, 1997). For example, in the automotive industry, competition is among Honda, Ford, Toyota, etc. and the supply chains that facilitate each of them to deliver finished product to the final customer. The expansion, design, production, marketing, and delivery of new cars is a team effort that begins with extracting raw materials from the earth, continues through design, fabrication, and assembly, and ends with fit and finish in the dealer's show room. Questions stay about how supply chains meaning and how deeply supply chain concepts are embedded in manufacturing organizations. Researchers investigated the factors needed to plan and construct effective supply chains (Childerhouse et al., 2002; Cooper and Ellram, 1993; Mabert and Venkataramanan, 1998; Narasimhan and Jayaram, 1998; Pagh and Cooper, 1998; Persson and Olhager, 2002; Walker et al., 1999, 2000). Giri and Sharma (2004) illustrated the strategies for improving the efficiency of supply chain such as benchmarking strategy, postponement strategy, redefining inventory and third party logistics. Nolan (1999) defined five individuality that help managers to collect the full benefits of the SCM approach. These engross achievable implementation phases, senior level involvement, collaboration, business process and organizational design, and effective presentation measures. These five steps help in the effective implementation of a SCM scheme. Ragatz et al. (1996) examined issues related to lean and agile supply chains as they examined the addition of suppliers with product development. Organizations are integrating their suppliers by linking them in product design and in some cases making them accountable for the design of components and systems that reduce product development time. A lean supply chain (LSC) employs incessant improvement efforts that focus on eliminating waste or non-value steps along the chain. As the rate of market change increases, the LSC approach has evolved into "multiple niche competition", which is the production of any quantity, even a single unit, combined with the ability to suit multiple market segments (Booth, 1996). In related work, Dowlatshahi (1996) focused on the early participation of logistics in product design. The author explored areas where early teamwork and interfaces between logistics and design activities could result in momentous

improvements for manufacturing enterprises. Dave and Saxena (2005) illustrated the distribution and logistics management practices and their crash on cost savings.

One of the most significant aspects touching the performance of a supply chain is the management of inventories, since the decisions taken in this esteem have a significant impact on material flow time, throughput and availability of products. Supply chain which involves the arrangement, coordination, and improvement of sequentially related set of operations in establishments, integrates technology and human reserve capacity for optimal management of operations to lessen inventory requirements and provide support to enterprises in pursuance of a spirited advantage in the marketplace.

### **2.1.1 Role of Inventory in a Supply Chain**

If we monitor closely, inventories can be found in all places. We don't know since when ants and squirrels are keeping inventories of their food supplies. And we don't recognize how they learned to keep an account of these inventories. Not only wildlife but also humans have been elegant enough to realize the benefits of inventories. Since stone-ages we have been carrying inventories and managing them. But, the development of current inventory management principles began when Harris (1913) derived the Economic Order Quantity (EOQ) formula. EOQ assumes that demand occurs at known, steady rate and supply fulfils the replenishment order after an unchanging lead-time. Unfortunately, the real world is not as perfect as that. In reality, demand rate is rarely stable; hard-to-predict market is common in most practical situations. Also, unpredictable events in supply systems can root unpredictable delays in replenishments. Moreover, in current time when outsourcing is at the centre phase, multifaceted and longer supply chains augment the length and variability of lead-times (Welborn, 2008). Although in the early days researchers acknowledged the necessity for considering uncertainties present in the real world, the precise work on inventory control models with stochastic features really began in 1950s. The classic book by Hadley and Whitin (1963) comprehends the research work done in this ground to that date. This fundamental research done in those early days

has had a critical effect on the subsequent developments in the ground of inventory theory.

Clark (1972) distinct various terms that occur in multi stage inventory theory. The author also breaks up the field of multi stage inventory control into its diverse parts. The field is very compound and the problems make use of various assumptions, e.g. demand type, number of items, type of product etc. Based on these assumptions, problems in multi-echelon inventory control fall into one of the following dichotomies: Deterministic - stochastic, single product - multi product, stationary - non-stationary, continuous review - periodic review, consumable product - renewable product and backlog - no backlog.

It is appealing to observe that though the author mentioned the objectives of the problems, they were either cost or customer service, none of the papers dealt with both together. The techniques of multi-criteria optimization were not used to attempt problems in this area till 1972. The paper is casual and does not present mathematical reviews of the papers surveyed. The vicinity of multi-echelon inventory theory can be divided generally into two groups - deterministic and stochastic. In the deterministic case it was assumed that the demand patterns of the customers are identified and fixed. In the stochastic case the demand patterns followed some probability distribution. Most of the early works in this field were deterministic. One of the earliest deterministic papers was by Evans (1958), in which a motionless inventory model with demands was analyzed. Zangwill (1966) extended this with a periodic review model. In the afterward works, Zangwill (1969) proved results for cases that did not comprise backlogging of the inventory. Veinott (1969) extended this study by considering the inventory model as a network model and presented a much simpler and competent solution. Kalymon (1970) later developed a decomposition algorithm to make it computationally practicable to solve the Zangwill-Veinott model. It is significant to note that as investigation proceeded into the solution of the deterministic multi-echelon problem, variety of assumptions were also being introduced into the model. The models with advanced solution techniques were likely to be most arborescent (each facility in the network had at most one predecessor). Even though most problems were integer or assorted integer problems, they were rehabilitated into

linear continuous problems for solution. When demand is deterministic, we know accurately when the reorder point is reached. When the demand is probabilistic, we cannot expect the exact point at which inventory would reach the reorder point. To decide when the inventory level reaches the reorder point, we can check the status of the system after every transaction. This technique is called “Transaction Reporting System”.

Research in stochastic multi echelon inventory theory has been chiefly applied on two stages systems. The majority of the papers consider the warehouse retailer case. There are a number of models considering this case (Muckstadt, 1979, Clark, 1972). Likewise Nahmais and Simth (1993) reviewed some of the work on the stochastic cases. Cachon (1996) presented accurate evaluations of a two echelon supply chain and found that the system cost increases if the upper echelon is required to carry no inventory or if the fill rate is high. The author also commented that the models that suppose continuous review do not do well if implemented in a periodic review environment. Zheng (1992) compared the stochastic inventory system to the conventional EOQ deterministic inventory system.

Ilaria et al. (2003) presented a methodology to describe a supply chain (SC) inventory management policy, which is based on the notion of echelon stock and fuzzy set theory. Manufacturers get hold of raw material from suppliers and route them into finished goods, and put up for sale the finished goods to distributors, then to retailer and/or customers. When an item moves through more than one phase before reaching the final customer, it forms a “multi-echelon” inventory system. A huge amount of researches on multi-echelon inventory control has appeared in the literature during the last decades. Clark and Scarf (1960) were the first to study the two-echelon inventory model. They proved the optimality of a base stock policy for the pure sequential inventory system and developed a well-organized decomposing technique to work out the optimal base stock ordering policy. Sherbrooke (1968) considered an ordering policy of two-echelon model for warehouse and seller. It is assumed that stock-outs at the retailers are entirely backlogged. Axsäter and Zhang (1999) considered two-echelon inventory structure with a central warehouse and a number of retailers. The retailers countenance an independent Poisson demand. Chou (2000)

showed that an included two-stage inventory model for deteriorating items with cooperative strategy results in higher profits. Though above models are valuable for real situation, their models are constrained to two stage inventory systems. Therefore, numerous researchers extended to more universal multi-echelon systems. Vander Heijden et al. (1997) developed stock allocation policies in general single-item and N-echelon sharing systems, where it is allowed to hold stock at all levels in the network. The objective is to achieve differentiated target customer service levels. Diks and de Kok (1998) determined a cost optimal replenishment policy for a divergent multi-echelon inventory system under periodic review order-up-to-policy. Iida (2001) considered a vibrant multi-echelon inventory model with non-stationary demands.

As supply chains broaden around the globe, and product life cycles grow up shorter, conventional inventory management processes have been rendered outdated (Peter Baker, 2007, Joseph B. et al., 2010). New operational demands dictate that companies incessantly manage inventory throughout multiple levels of global supply chains to optimize performance against business objectives (Brent and Travis, 2008). Increasing globalization has tended to direct to longer supply lead-times, which, by conventional inventory control theory, result in greater levels of inventory to provide the similar service levels. However, there has been some concern about the true costs of inventory and whether companies do in fact identify these fully. For example, Christopher (2005) highlighted costs such as storage, obsolescence, damage, deterioration, shrinkage, insurance and management costs, as well as the more traditional cost of capital. There is thus a stress on inventory lessening in each of these supply chain classifications. Biju Kr. et al. (2009) covered the geographical risks for inventory strategies and their impact on supply chain with the help of a case study. There have been many new developments in the area of supply chain inventory management, particularly those pertaining to cost reduction, customer demand and lead-time responsiveness. Nath et al. (2008) explained how to direct the customer experiences and their impacts in managing resources. Rai et al. (2009) illustrated the implications of retail chains and new developments regarding the supply of agriculture products to the supermarkets. Suzanne et al. (2004) proposed a framework for prioritizing lead-time reduction in a demand chain improvement project, using a

typology of demand chains to make out and recommend trajectories to attain desirable levels of market mediation performance.

### **2.1.2 Uncertainties Affecting Supply Chain performance and Inventory Control**

In the existence of uncertainties, it is tricky to foresee the final effects of the actions taken and hence to direct the inventories efficiently. A number of works have devoted to study supply chain management under uncertain environments. For example, Gupta and Maranas (2000), Gupta et al. (2003) incorporated the uncertain demand via a normal probability function and recommended a two-stage solution framework. Gupta & Maranas (2003), Tsiakis et al. (2001) used scenario planning approach to explain demand uncertainties. Therein a number of demand scenarios with assigned non-zero probabilities are used as separate stochastic demand quantities. All scenarios are concurrently taken into account in the supply chain network design. However, the robustness of conclusion to uncertain product demands is not considered in these studies. Due to the potential of dealing with linguistic expressions and unsure issues (Petrovic et al., 1998) used fuzzy sets to handle uncertain demands and external raw material problems, and further considering uncertain supply deliveries in a later work (Chen et al., 2010, Petrovic et al., 1999). Giannoccaro et al. (2003) also applied fuzzy sets theory to model the uncertainties associated with both market demand and inventory costs. An article by Lee (1987) presented ‘the uncertainty framework’, which considers dimensions of demand and supply uncertainties. This framework can be a straightforward but powerful way to differentiate a product; which can be useful in devising a suitable supply chain strategy for that product. Uncertainties in demand and supply can effect in too much inventories and deteriorated customer service, indicating out of control supply chain (Tomlin, 2009). In general, it is observed that stochastic lead-times and demand have their maximum impact in combination. In this era of outsourcing and/or off-shoring longer lead-times are widespread, especially because the transportation time might be considerable. Usually, extended lead-times and uncertain demand hamper the performance of inventory control systems. Also, there are hardly any supply processes

which have entirely avoided the issues of limited capacity and unpredictable quality. These issues have even more pronounced effects in the presence of stochastic lead-times. Hence, considering additional stochastic features in inventory control models will bring our study closer to practical problems.

In today's ever changing markets, maintaining a well-organized and flexible supply chain is critical for every enterprise, particularly given the prevailing volatilities in the business situation with continually shifting and increasing customer expectations. The upstream and downstream coordination engendered by supply chain management with the goal of minimizing uncertainty and variations along the supply chain shows that businesses can no longer wait for that the objective of business can be met just by becoming efficient in itself. Variety of sources of uncertainty can be acknowledged in these systems. Based on the timeframe over which these uncertainties have an effect on the system, they can be categorized into short-term or long term uncertainties (Subrahmanyam et al., 1994). Short-term uncertainties may comprise day-to-day processing variations, cancelled/rushed orders, equipment failure, etc. Long-term uncertainty refers to raw material/final product unit price fluctuations, seasonal demand variations and production rate changes happening over longer time frames. Underestimating uncertainty and its impact can show the way to planning decisions that neither defend a company against the threats nor take benefit of the opportunities that higher levels of uncertainty provide. For example, one of the input sources of uncertainty in any production-distribution system is the product demand. Failure to account for significant demand fluctuations could either lead to unsatisfied customer demand translating to loss of market share or extremely high inventory holding costs both highly unwanted scenarios in the existing market settings where the revenue margins are tremendously tight. The previous scenario corresponds to a failure in recognizing an opportunity to capture extra market share while the later translates to a failure in effectively managing the downside threat exposure of the company. Deterministic planning models, which do not distinguish the uncertainty in the future demand forecasts, can thus be predictable to result in inferior planning decisions as compared to models that explicitly account for the uncertainty.

The complex and dynamic interactions between supply chain entities lead to substantial uncertainty in planning. Uncertainty tends to proliferate up and down the supply chain and this affects supply chain performance. Davis (1993) identified three distinct sources of uncertainty in supply chains: supply uncertainty, process uncertainty, and demand uncertainty. Supply uncertainty is caused by the variability of supplier presentation due to late or defective deliveries. Process uncertainty results from the unpredictability of the production process due to machine breakdowns. Finally, demand uncertainty which according to Davis (1993) is the most serious of the three, arises from unstable demand or inaccurate forecasts. The author also discussed numerous metrics for measuring the three types of uncertainties. Levy (1995) reported results from a case study and a simulation model to show that demand associated disruptions in an international supply chain created considerable costs of inventory holding, expediting and lower demand fulfillment.

Cooperation among supply chain members is required for efficient SCM and managing inventories (Ellarm and Cooper, 1990; Tyndall et al., 1998). Cooperation refers to comparable or complimentary, coordinated activities performed by firms in a business relationship to produce superior shared outcomes or singular outcomes that are mutually expected over time (Anderson and Narus, 1990). Cooperation is not limited to the needs of the existing transactions and happens at various management levels (e.g., both top and operational managers), involving cross-functional synchronization across the supply chain members (Cooper et al., 1997).

### **2.1.3 Relationship amongst Supply Chain Members in Controlling Uncertainties**

Combined action in close relationships refers to carrying out the crucial activities in a cooperative or coordinated way (Heide and John, 1990). Cooperation starts with combined planning and ends with joint control activities to assess performance of the supply chain members, as well as supply chain as a whole (Cooper et al., 1997; Ellarm and Cooper, 1990; Spekman, 1988; Tyndall et al., 1998). Joint planning and assessment engage ongoing processes over multiple years (Cooper et al., 1997). In addition to planning and control, cooperation is needed to decrease supply

chain inventories and pursue supply chain- wide cost efficiencies (Cooper et al., 1997; Dowst, 1988). Lasser and Zinn (1995) suggested that successful relationships aim to put jointly supply chain policy to avoid idleness and partly cover, while seeking a level of collaboration that allows participants to be more efficient at lower cost levels. Effective SCM is made up of a series of partnerships and, thus, SCM requires partners to make and uphold long term relationships (Cooper et al., 1997; Ellarm and Cooper, 1990).

Although not general to all those industries which are having a big and strong supply chain environment, there has been a general shift of power from manufacturers to retailers over the last two decades (Fredrik Olsson, 2008). Lateral transshipments between stocking locations are used to enhance cost efficiency and get better customer service in dissimilar ways. There are basically two main approaches to capture the impact of transshipments between stocking locations. Within the first approach, transshipments are used after the demand is observed but before it is fulfilled. If there is surplus demand at some of the stocking locations while some have surplus inventory, lateral transshipments between stocking locations can work as an enhancement mechanism. Moreover, pooling the stocks can be viewed as a secondary resource of supply for inventory shortages, especially when transshipments between stocking locations are more rapid and less costly than emergency shipments from a central depot or backlogging of surfeit demand. This approach is termed as emergency lateral transshipment (ELT). Starting with Krishnan and Rao (1965), a large portion of the transshipment literature is dedicated to models of such emergency transshipment models. Herer and Rashit (1999), Robinson (1990), Tagaras (1989, 1999), and Tagaras and Cohen (1992) analyzed such models. An optional way of analyzing the impact of transshipments between stocking locations is to judge it as a tool to balance inventory levels of stocking locations during order cycles. To guarantee a certain level of customer service in all stocking locations, it is pretty to keep the inventory position at each location in balance relative to each other. This way of transshipment is called preventive lateral transshipment (PLT). Inventory levels can become disturbed due to random variations in demand, where the term imbalance refers to the deviation of the inventory position of stocking locations from the standard inventory position (Diks and de Kok, 1996). Permitting transshipments

between locations during the system order cycle will budge the system stock before demand is observed. Such redistribution will diminish the total expected shortages and will supplement the service level.

In emergency models, transshipments react to real shortages. However, the reason of redistributing inventory before the realization of demand is to decrease the risk of probable future shortages. Tagaras (1999), therefore, refers to these models as precautionary models. Bertrand and Bookbinder (1998), Diks and de Kok (1996), Hoadley and Heyman (1977), and Jönsson and Silver (1987) analyzed such models. One of the first papers, which mentioned the transshipment problem, was Clark and Scarf (1960). However, they ignored the problem due to the mathematical intricacy. In another early paper, Krishnan and Rao (1965) developed a periodic review, single-echelon model in which they authorized transshipments between the lower echelon stock facilities. Multi-location inventory problems with general transshipment amongst the retail stores have been analyzed by number of authors. Gross (1963), Das (1975), Karmarkar and Patel (1977), Tagaras (1989), and Tagaras and Cohen (1992) analyzed two-location transshipment problems. Other researchers have analyzed transshipment models for more than two locations. Karmarkar (1987) developed limits for a common model where transshipments are a substitute to ordering. Robinson (1990) derived structural results for a model with general transshipments amongst multiple indistinguishable retail stores. However, Robinson's model can only be solved methodically if all cost parameters are impossible to differentiate, thus the model is not appropriate to observe the asymmetric structure of our integrated supply-chain problem. Lee (1987) derived expressions that estimated the fractions of demands that can be satisfied by stock on hand, ELT, and backordering, and in doing so, proved that applying lateral transshipment reduces total cost. Herer and Rashit (1999) studied transshipment with unchanging and joint replenishment costs, but simply with single period. Minner and Silver (2005) considered a distribution system with two matching locations, in which lateral transshipments are allowed. Tagaras (1999) projected random and risk-balancing policies. He organized many scenarios and evaluated them by the total expected cost and fulfill rate.

Axsäter (1990) analyzed a system analogous to that of Lee (1987) but with the modification of assuming that warehouses within each group are not the same. The reorganization policy proposed by Bertrand and Bookbinder (1998) adjusted stock to accomplish equal marginal cost over all retailers just before the replenishment phase. This method has the negative aspect of not being intelligent to react to stock-out before redistribution because the redistribution policy is only performed at the end of the replenishment period. Lateral transshipment based on easiness of use, one of two kinds of policies proposed by Banerjee et al. (2003), redistributed reserve to retailers with less than desirable levels until all stock is exhausted. However, this policy is problematic when desired stock levels are determined imperfectly. Some researchers have attempted heuristic approximations and/or simulation/ logistics approaches to conquer the intricacy involved with analytical modeling and solving multi-echelon supply chain problems (Banerjee et al., 2003; Burton and Banerjee, 2005; Pedro M. Reyes, 2006). Finding accurate solutions to such problems can be extremely time-consuming and not easy to implement in practice (Axsäter, 2003).

A small number of models (e.g., Bertrand and Bookbinder, 1998; Diks and de Kok, 1996; and Jönsson and Silver, 1987) guaranteed a convinced level of service while minimizing total cost. Krishnan and Rao (1965) considered a solitary item inventory distribution system where the item can be stored in each of the  $N$  stocking locations that are supplied by an upper echelon common source with never-ending capacity. Assuming self-governing stochastic demand, they model the transshipment problem for endless horizon. Their model shows the pooling benefit of transferring surplus inventory of one retailer to the one with surfeit demand. The literature on transshipments was latent until the paper by Hoadley and Heyman (1977), which extends the indistinguishable cost model of Krishnan and Rao (1965) to a two echelon model with returns and transshipments, where preventive transshipments are executed before the understanding of demand. Jönsson and Silver (1987) integrated non-negligible replenishment lead-times and transshipment lead-times between stocking locations to Hoadley and Heyman's model. Lead-times from the central depot to the stocking locations are the same to the transshipment lead-time among stocking locations. However, there is also a non-zero replenishment lead-time from an outside supplier to the central depot. Tagaras (1989) extended Krishnan and Rao's model by

allowing non-identical costs at two locations. Absolute pooling was considered which states that if there is a financial incentive to transship one item, and then the utmost amount is sent. By considering non-zero replenishment lead-times (while lateral transshipments are still instantaneous), Tagaras and Cohen (1992) analyzed dissimilar pooling policies in terms of expected cost per period, comparing complete pooling with partial pooling, the practice of holding back some stock to hedge against demand uncertainty. Author(s) proposed an estimated model and a heuristic algorithm based on the observation that the safety factor of a location's optimal order-up-to level is self-governing of the replenishment lead-times. Furthermore, Tagaras (1999) extended the two-location model with replenishment lead-times to three identical stocking locations. In addition to determining the order-up-to quantities for the stocking locations, Tagaras also analyzed the impact of dissimilar transshipment policies when one or two locations face a shortage. With fixed replenishment costs, Herer and Rashit (1999) solved the single-period model for two stocking locations with non-identical cost structures. Herer and Tzur (2001, 2003) developed most favorable and heuristic algorithms for the active transshipment problem incorporating fixed replenishment and transshipment costs with a deterministic demand structure for restricted horizon.

In the literature, few inventory models sufficiently address the multi-location, multi-period stochastic inventory system with emergency transshipments. Most research focuses on a single period study of multi-location inventory systems where transshipments are used as a preventative measure to balance the inventory levels at the stores. Allen (1958) considered the problem of stock redistribution to minimize transshipment and shortage costs. Gross (1963) determined both finest redistribution and replenishments policies for a two-store inventory system. Das (1975) studied alike system where transshipments are allowed at certain predetermined times in a period. Hoadley and Heyman (1977) developed a general single period model that allows for stock purchasing and disposing at the warehouse, returning or shipping items between the warehouse and different stores, and transshipments amongst the stores. Karmarkar and Patel (1977) reexamined the two location problem of Gross (1963) and developed a simpler solution procedure. Karmarkar (1979) also provided a qualitative study of the more general convex programming problems. Structural

properties and computational issues related with the general multi-period inventory problems were discussed by Karmarkar (1987, 1979).

Tagaras (1989) extended the two-location version of Krishnan and Rao's model by allowing dissimilar service level constraints. Robinson (1990) examined the general case of numerous locations with different cost parameters, maintaining the assumptions of immediate replenishment and transshipment, and proved the optimality of the base stock ordering policy. However, the optimal order-up-to points can be found critically only when there are only two outlets. For the general case Robinson (1990) proposed a heuristic explanation technique employing Monte Carlo integration. Archibald et al. (1997) measured a modification of the two-location problem, where emergency transshipments can take place at any time during a period, instead of only at the end of the period. Much transshipment may occur during a period and the total demand is not known when any transshipment occurs. An alternative to transshipment is an emergency order from the central warehouse, which also arrives instantaneously but it costs more than a lateral transfer. Archibald et al. (1997) derived the form of the most favorable policy for that model. The ordering policy is of the base stock type, while the result whether to place an emergency order or to use lateral transshipment depends on the costs, the residual time in the period and the accessible inventory at the another location. Tagaras and Cohen (1992) resorted to simulation in order to learn the two-retailer inventory system with non-negligible replenishment lead-times and uneven cost parameters. Author(s) mainly found that entire pooling is still better to fractional pooling, i.e. transshipment policies using objective and/or reserves stock levels. Tagaras and Cohen (1992) also provided approximations for the expected on-hand inventories, backorders and transshipments, as well as a heuristic algorithm for determination of near-optimal order-up-to quantities entire pooling. Cachon and Zipking (1997) studied competitive and supportive inventory policies in two stage supply chain. Lariviere (1998) studied supply chain contracting and coordination with stochastic demand. Tagaras (1999) studied pooling in multi locations distributions system and get some practical results such as (a) advantage of pooling increases with increase the pooled location (b) the type of transshipment policy in case of shortage does not affect appreciably the

system performance (c) it is preferable to form a unbiased pooling group consisting of location that face similar demand.

Jönsson and Silver (1987) examined a centralized ordering inventory system with emphasis on adjusting the inequity of inventory levels at the stores through stock redistribution. It has been assumed that a base stock replenishment policy and a prearranged order cycle of certain time periods considering an absolute redistribution of stocks one period before the end of an order cycle to balance the inventory levels at all stores. It is shown that a considerable lessening in safety stock is possible by using redistribution. In many sensible operations familiar to the authors, transshipments are used as an emergency measure to out of stock situations after demands are realized. Krishnan and Rao (1965) considered the determination of optimal base stock levels that would minimize the one-period inventory and transportation costs for inventory systems with emergency transshipments. Robinson (1990) extended the existing analysis of optimal base stock levels to allow for multiple periods and varying costs across the stores. Individual ordering at each store according to base stock policies has been considered, and near optimal ordering and transshipment policies using a linear programming approximation was obtained. Pasternack and Drezner (1991) considered the determination of optimal base stock policies for two substitutable products in a single period inventory analysis. This problem is very similar to a two-location inventory system with transshipments. Cohen et al. (1986) considered a complex multi-echelon inventory system for managing low-demand, high-value items. Author(s) developed a one-period inventory model that considered pooling mechanisms for shortages, emergency and normal replenishments and stock repositioning. Transshipments are allowed only among the locations belonging to a “location grouping”. Near-optimal base stock policies were obtained for different locations subject to a service level constraint. Extensions to (s; S)-type policies were considered by Cohen et al. (1992). Tagaras and Cohen (1992) discussed the possible effects of replenishment lead-times on pooling policies. A simulation analysis was performed on different pooling policies for a two-location inventory system. Tagaras and Vlachos (2002) investigated the operational characteristics of a pooling group of two stocking locations supplied periodically by a central warehouse leading to a conclusion through simulation showing the substantial benefits of risk pooling when

only the demand is highly variable. Evers (1997) used a simulation model to examine whether emergency transshipments outperform split orders. Based on a portfolio effect model Evers (1999) also examined emergency transshipments between stock-keeping facilities. Hong-Minh (2000) considered the dynamical effect of lateral emergency transshipments within a supply chain. Xu et al. (2003) estimated customer service in a two location continuous review inventory model with emergency transshipments. Herer and Rashit (1999) addressed the problem of inventory management in a two-location inventory system with emergency supply after demand has been realized.

#### **2.1.4 Auto Sector Supply Chain (International Scenario)**

From the 1950s onwards, different countries used import substitution industrialization policies to bear the growth of their domestic auto industries. Current emphasis on worldwide climate change is increasing stress on automotive executives to make the precise decisions in many areas, including R&D, manufacturing, dealing with uncertainties and related to new management policies like lateral transshipment. These challenges strike an industry already plagued with prominent costs, short profit margins, and accelerating competition. In this active business atmosphere, a superior supply chain and its implementation to control uncertainties is one significant part to help automakers distinguish themselves from the competition. In fact, many of the trends particularly lateral transshipment in the auto industry are reinforcing the need to redefine supply chain strategies, layouts, and operations. In a highly competitive environment, an effectual and well-organized supply chain is a must for automotive manufacturers at global level. The auto industry landscape is uncovered to a set of significant challenges and trends that are leading, if not accelerating, the need to fine-tune uncertainties and their controlling techniques and operations even further. The increasing requirement for managing uncertainties, lateral transshipments, real-time information and effective communication across the supply chain network are critical for managing and optimizing the supply chain on a flexible basis, while keeping costs under control. The automotive manufacturing industry is an extremely competitive one and many automobile players are focusing on their supply chains in global

perspectives for sources of competitive advantage. In order to raise profits and customer satisfaction, many international auto players (Ford, Honda, Suzuki and Toyota etc.) are implementing lateral transshipment approach for controlling uncertainties at different echelons in their supply chain which is a topic receiving a great deal of attention in the industry today. The augment in competitive pressure in the business environment has resulted in SCM becoming a serious component of most new competitive strategy models. The automotive industry includes multiple players in extensive, complicated, global supply chains. According to Treleven et al. (2000) many auto companies are using SCM improvements as a constituent of a quick response implementation around the world. The relationships within the automotive supply chains (lateral transshipment) tend to be fixed and clearly demarcated. Thus, immense potential exists for shaping the relationships between these players to make them more interactive. The industry tendency to decrease inventory levels quickly is forcing automotive companies to refurbish and expand their SCM initiatives. Improving partnerships (transshipments) along the supply chain seems to have significantly helped in the development of automakers. Swaminathan (2001) stated, “inventory reduction and partnership improvement are the major benefits of implementing supply chain management”. Bland (2003) clarified that managers understand that SCM is providing a competitive edge for their enterprises. All automakers in different countries are continually under anxiety to identify consumer preferences, national biases, and new market segments where they can sell vehicles and gain market share. Their ability to be flexible enough to quickly respond to all these pressures is determining their future in the industry. The implications of these factors are immeasurable and spread along the supply chain of the automakers. SCM is a best-in-class, high-performance solution which can be utilized by the world’s leading automobile manufacturer, logistics and distribution companies, and retailers to merge the demand chain with the supply chain. Globally automobile companies face challenges in the field of SC execution (lateral transshipment) at different levels beyond the organization boundaries and logistics requirements within the limited operating environments.

### **2.1.5 Supply Chain in Indian Automobile Industry**

On the canvas of the Indian economy, auto industry occupies a prominent place. Due to its deep forward and backward linkages with several key segments of the economy, automotive industry has a strong multiplier effect and is capable of being the driver of economic growth. A sound transportation system plays an essential role in the country's speedy economic and industrial development. The well-developed Indian automotive industry skillfully fulfils this catalytic role by producing a broad variety of vehicles: passenger cars, light, medium and heavy commercial vehicles, multi-utility vehicles such as jeeps, scooters, motorcycles, mopeds, three wheelers, tractors etc. India's quest to become a worldwide auto-manufacturing hub has made the world's top automakers increasingly turn to India for their vehicle components. Riding this achievement and capitalizing on the strengthening demand from domestic auto companies, the Indian auto industry is intensifying the demand and is emerging as one of fastest growing manufacturing sectors, and a worldwide competitive one (Kamala and Doreswamy, 2007) . However, there is still a lack of noteworthy study of supply chain practices and its presentation in developing countries, in general and India, in particular (Austin, 1990). Many dominant factors affect decisions made in the automotive world. Consumer preferences decide the current styles, consistency, and presentation standards of vehicles. Government trade, safety, and environmental regulations found incentives and requirements for upgrading and change in design or production. Competitive rivalries and corporate strategies provide equally important momentum for research, design innovations, and changes in the manufacturing process. All automakers are continually under pressure to recognize consumer preferences, national biases, and new market segments where they can sell vehicles and gain market share. Their capability to be stretchy enough to quickly react to all these pressures is determining their prospect in the industry. The implications of these factors are enormous and propagate along the supply chain of the automakers in India. The automotive manufacturing business in India is a tremendously competitive one. Many companies are focusing on their supply chains for sources of competitive advantage and to overcome related uncertainties. The

industry inclination to lessen inventory levels rapidly is forcing automotive companies to redesign and expand their SCM initiatives (Indian Ministry of Commerce and Industry, 2002). Efficient SCM involves building faith and relationships amongst members and with long-standing suppliers, whom are confidentially included in the growth and production of components. Improving partnerships (lateral transshipment) along the supply chain seems to have considerably helped the expansion of automakers.

The automobile industry has undergone significant structural and other changes in the last decade or so. The industry is also facing increasing outside competition from the public transport sector, as customers re-evaluate their personal vehicle usage (IBIS World News letter, 2008). Saad and Patel (2002, 2006) concluded that Indian automobile sector seems to be still characterized by the following factors; integration among the partners (lateral transshipment) is still in its childhood and in a majority of the auto companies in India it is in the primary stage; assemblers are still considered as the chief competitive units, rather than the whole supply chain including (at least) the first tier component suppliers; uncertainties like demand and lead-time need more control. Srinivas and Shekhar (1997) also covered the uncertainties faced by Indian automobile industry via stochastic simulation experiments. Singh et al. (2007) examined the strategies adopted for cost reduction, inventory control, quality improvement and competency development on Indian auto component sector.

The challenges faced by automobile manufacturers and suppliers comprise controlling uncertainties, improving quality, meeting cost reduction targets, exploring lateral transshipment and developing time to market. All these are driving the organizations towards better product demarcation using cutting edge R&D, pioneering sales and marketing approaches, and increasing focus on boosting efficiencies in manufacturing and supply chain. Hence, in the age of e-business and worldwide outsourcing, supply chain management (SCM) plays a vital role in many of these areas. SCM is a best-in-class, high-performance solution which can be utilized by the world's leading automobile manufacturer, logistics and distribution companies, and retailers to merge the demand chain with the supply chain. Indian automobile and

auto components industry is on a roll and there is a vast scope for management for enhancing the lateral transshipment approach in controlling the uncertainties of inventory control in the supply chain.

## **2.2 LIMITATIONS/GAPS OF EXISTING WORK**

After making a comprehensive investigation into the reported literature, following limitations/gaps have been observed and need to be addressed.

- Most of the researchers have dealt with the higher echelon of the supply chain therefore lower echelon needs more exploration and attention. Internal issues in a Supply Chain are more focused in the reported work, integration of external suppliers and customers will add new opportunities for successful implementation and improving the results.
- Many supply chains do not track uncertainties such as demand fluctuations, suppliers' delivery times, the quality of incoming materials, manufacturing process time, transit times, and so on. This leads to non-optimal stocking levels. Uncertainties like stochastic demand, delivery lead-time need to be explored more and more as these have through crash on inventories.
- Demand for some items becomes more unsurprising as products grow-up; demand for others becomes more volatile. Inventory needs for some components stabilize as multiple products use common parts. Less work has been done in this regard and hence inventory stocking policies should be occasionally adjusted to reproduce such changes.
- From the literature it has been found that supply chain's overall performance depends on the joint activities at all echelons, usually each entity is managed by fairly independent management teams, each with its own objectives and assignment. The consequence is that there is diversity in goals that, if met, result in inefficiencies for the overall chain.

- Lateral transshipment has found prominent place in literature however some limitations exists, like arbitrary choice amongst retailers, pooling between limited number of retailers, transshipment started with retailer having highest stock in hand or having lesser number of outstanding orders and sometimes it has been done unidirectional. Additionally, fixed numbers of items are to be transshipped and up to the reorder level, same delivery lead-time, constant holding, backorder and transshipment costs as well as constant demand faced by the retailers have been considered.
- India is a growing country, and interestingly, there has been an escalating trend of realisation of SC optimisation therefore auto manufacturers in India and all tiers of the SC have massive opportunities to enhance their intact supply chain process with the successful implementation of SCM solutions. By exploring Indian automobile sector, it has been found that uncertainties like demand and lead-time have direct impact on managing inventories. Customer satisfaction and cost reduction are again the key issues to be handled effectively and efficiently. SC solutions have been implemented successfully on higher echelon of automobile industries but the lower ones need more exploitation as these are still beyond the boundaries of SC implementation. There exists a vast scope for Indian automobile and auto component manufacturers to reduce their logistics costs with the execution of SCM solutions.

Hence, it has been concluded from the reported literature that inventory control, uncertainties and lateral transshipment are becoming attractive preference for researchers in a supply chain. Implementation of lateral transshipment is still the key issue related to inventory management and cost reduction in SCM environment.

Next chapter explains the problem description, methodology adopted and the verification of the developed program with the help of an example problem.

### PROBLEM FORMULATION AND METHODOLOGY

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#### 3.1 PROBLEM STATEMENT

Physical pooling of inventories has been widely used in practice to reduce the cost and improve customer service, therefore in this work the impact of lateral transshipment on supply chain performance is studied in overcoming the uncertainties of demand and lead-time to reduce inventories at retailers' end. It also aims to assess the relationship amongst retailers, which constitute lowest echelon level in a supply chain just before the actual customers. Discrepancies between the locations' observed demand and their available inventory may be corrected through transshipments. Inventory system of automobiles manufacturing companies in India has been considered that operates multiple retailers for the sale of their products. The system uses a periodic-review inventory control policy. Every day, the retailers order replenishment automobiles based on the total inventory available and reorder point. The external demand at each retailer comes from independent customers for the products. A model has been formulated considering one central warehouse catering  $n$  retailers with range of products ( $\lambda$ ) having variable costs (holding, stock-out and effective transshipment) amongst them considering the effect of geographical characteristics, size of the stocking location, material handling efficiency as well as the retailers' locations. The events in any period are sequenced in terms of delivery, demand, review, transshipment, and order. Ordering cost is exempted as it is more or less constant for all number of orders. Demand not satisfied after transshipment is considered as stock-out. Each retailer faces normally distributed random demand pattern, demand at every retail outlet is independent of other's demand. Lead-time is also normally distributed and independent of other retailer's lead-time. Demand and period service levels measure the performance of the system. Above mentioned formulated model is used to develop a program in C++ for optimum cost and inventory associated in a supply chain at retailers' level. For the verification and evaluation of the developed program, the same has been run on an example problem

in which data has been set randomly. The similar program is then run on the actual data of three automobile manufacturing companies and the results have been compared with the existing one. In the next section we'll discuss some assumptions that have been used for the development of the model followed by the general model.

## **3.2. MODEL FORMULATION**

### **3.2.1 Assumptions used**

Following assumptions have been used in the formulation of the model:

- Fixed numbers of units have been supplied to retailers from central warehouse.
- N numbers of products have been assumed at retailers' end.
- No additional quantities are transshipped from warehouse to retailers in case of stock-out.
- Surplus quantities are hold by retailers after fulfilling the demand.
- Emergency transshipments are only made to satisfy actual current demand and not to made build-up inventory.
- Emergency transshipment quantities depend upon pre-transshipment inventory and observed demand.
- Emergency transshipment is assumed to be based on distance.
- Emergency Transshipment takes place on the same day.
- Any demand that is not satisfied after transshipment is considered as stock-out.
- The series of events in any period is delivery, demand, review, transshipment, and order.
- Model allows complete pooling between retail outlets for  $\lambda$  numbers of products.
- The retailers have variable holding, stock-out and transshipment costs per unit amongst them.
- Effective transshipment cost amongst retailers has been considered.

- Holding and shortage costs are based on a retailers' ending day inventory level.
- Model assumes periodic review inventory control policy.
- Normally distributed random demand and lead-time have been assumed.
- Demand and lead-time at every retail outlet are independent of other's demand and lead-time.
- Each retailer faces demand from independent customers for the products.
- Demands are fulfilled as first-in first-out (FIFO) at retailers' end.

Based upon the above mentioned assumptions the model has been formulated as under:

### 3.2.2 Mathematical Description

We shall be interested primarily in the control of supply chain-inventory system for manufacturing industries. A more restricted objective of the control of inventory is to satisfy the customer by meeting the schedule for deliveries. Failure of deliver order on time is one principal cause of loss of business and customers. Inventories are thus a necessary part of the contemporary manufacturing environment, and they must be managed if profits are to accrue.

The required mathematical relations for calculating the inventory levels are as follows:

- a) Maximum level of inventory is given as:

$$I_{max} = (T_r + T_{Lmax})\mu_{dmean} \quad (1)$$

This equation is for longer lead-times and moderate demand fluctuations (more than 6 days) and if the span of lead-time is short (1-2 days) then maximum level of inventory may be calculated as:

$$I_{max} = (T_r + T_{Lmin})\mu_{dmean} \quad (1a)$$

Similarly for the cases when demand is highly fluctuating then maximum level of inventory may be calculated as:

$$I_{max} = (T_r + T_{Lmax})\mu_{dmax} \quad (1b)$$

where  $T_r$ ,  $T_{Lmax}$ ,  $T_{Lmin}$ ,  $\mu_{dmean}$  and  $\mu_{dmax}$  represent review period, maximum lead-time, minimum lead-time, mean demand and maximum demand respectively (Armah, <http://www.warmah.com>).

If different products are represented by  $\lambda$  then the maximum level of inventory for  $\lambda$  products is given as:

$$I_{max\lambda} = (T_{r\lambda} + T_{Lmax\lambda})\mu_{dmean\lambda} \text{ where } \lambda = 1, 2, 3 \dots \dots m \quad (2)$$

b) Mean demand may be calculated as:

$$\mu_{dmean} = Total\ demand / No.\ of\ days\ or\ periods \quad (3)$$

c) Demand variation of  $i^{th}$  retailer for  $\lambda$  products, which is based on normal distribution, may be calculated as follows:

$$\mu_{dmax}^i = \mu_{dmean}^i + 3\sigma_{i\lambda} \text{ and } \mu_{dmin}^i = \mu_{dmean}^i - 3\sigma_{i\lambda} \quad (4)$$

here  $i$  can vary from 1, 2, 3, ... ..  $n$  retailers.

$\mu_{dmax}^i$ ,  $\mu_{dmin}^i$ ,  $\mu_{dmean}^i$  and  $\sigma_{i\lambda}$  represent maximum, minimum, mean demand and their standard deviation of  $i^{th}$  retailer for  $\lambda$  products.

d)  $\sigma$  is the standard deviation and may be calculated as square root of the mean of the squares of the differences of the variate values from their mean and may be shown as:

$$\sigma = \sqrt{\sum \frac{(\mu^i - \mu_{dmean}^i)^2}{N_T^i}} \quad (5)$$

e) Mean lead-time may be calculated as:

$$T_{Lmean} = Total\ lead - time / No.\ of\ days\ or\ periods \quad (6)$$

f) Similarly the span of lead-time of  $i^{th}$  retailer for  $\lambda$  products may be calculated as:

$$T_{Lmax}^i_{\lambda} = T_{Lmean}^i_{\lambda} + 3\sigma^i_{\lambda} \text{ and } T_{Lmin}^i_{\lambda} = T_{Lmean}^i_{\lambda} - 3\sigma^i_{\lambda} \quad (7)$$

g) Different retailers are having different capacity to hold maximum inventory due to individual constraints. Therefore maximum inventory for  $\lambda$  products is:

$$I_{max\lambda}^i = (T_{r\lambda}^i + T_{Lmax}^i_{\lambda})\mu_{dmean}^i_{\lambda} \quad (2a)$$

h) When inventory level touches or falls below reorder level i.e.  $I^i \leq Q_R^i$ , then an order is placed. Reorder level is used as a trigger or flag to set up a new order. To calculate the reorder level, the firm will need to know how much time it takes for its supplier to deliver a new order. So, reorder level may be calculated as (Sidola, 2004):

$$Q_{R\lambda}^i = T_{Lmean}^i_{\lambda} \mu_{dmean}^i_{\lambda} \quad (8)$$

Sometimes when lead-time is very short in that case reorder level may also be considered as safety stock which is equal to:

$$Q_{S\lambda}^i = T_{Lmin}^i_{\lambda} \mu_{dmin}^i_{\lambda} \quad (9)$$

and for highly fluctuating demands it is:

$$Q_{R\lambda}^i = T_{Lmean}^i_{\lambda} \mu_{dmax}^i_{\lambda} \quad (9a)$$

i) To calculate the quantity ordered by the retailer  $i$ , in-transit inventory is also considered. Therefore ordered quantity may be calculated as (Sidola, 2004):

$$Q_{o\lambda}^i = I_{max\lambda}^i - (Q_{t\lambda}^i + Q_{h\lambda}^i) \quad (10)$$

where  $Q_{t\lambda}^i$ ,  $Q_{h\lambda}^i$  represents the in-transit and surplus inventory respectively of  $i^{th}$  retailer for  $\lambda$  products.

Inventory may include three main types of costs. These are the costs to carry standard inventories and safety stock i.e. holding cost, shortfall or stock-out cost and emergency transshipment cost. In general total cost also consists of the transportation cost from the central warehouse and the same is used in the present model to calculate the effective transshipment cost amongst  $n$  retailers.

j) Expected holding cost is given as:

$$C_{h\lambda}^i = \sum_{i=1}^n \sum_{\lambda=1}^m c_{h\lambda}^i Q_{h\lambda}^i \quad (11)$$

where  $C_{h\lambda}^i$ ,  $c_{h\lambda}^i$  and  $Q_{h\lambda}^i$  represents the total holding cost of retailer  $i$  for  $\lambda$  products, unit holding cost and total no. of holding or surplus units respectively.

k) Stock-out cost is given as:

$$C_{st\lambda}^i = \sum_{i=1}^n \sum_{\lambda=1}^m c_{st\lambda}^i Q_{st\lambda}^i \quad (12)$$

where  $C_{st\lambda}^i$ ,  $c_{st\lambda}^i$  and  $Q_{st\lambda}^i$  represents the total stock-out cost of retailer  $i$  for  $\lambda$  products, unit penalty cost and stock-out quantities respectively.

l) Expected cost of lateral transshipment is given by:

$$C_{ts\lambda}^{ij} = c_{ts\lambda}^i d_{\lambda}^{ij} Q_{(LTS)\lambda}^{ij} \quad (13)$$

(Transshipment with  $d_{ij}$  minimum will be preferred)

$C_{ts\lambda}^{ij}$ ,  $c_{ts\lambda}^i$ ,  $d_{\lambda}^{ij}$  and  $Q_{(LTS)\lambda}^{ij}$  represents the total transshipment cost of retailer  $i$  for  $\lambda$  products, transshipment cost per unit per unit distance, distance between  $i^{th}$  and  $j^{th}$  retailer and lateral transshipment quantities respectively.

If  $C^i$  is the replenishment cost per unit for retailer  $i$  from central warehouse then effective transshipment cost between retailers  $i$  and  $j$  is given as (Herer et al., 2006):

$$\hat{C}_{ts\lambda}^{ij} = (C_{\lambda}^i + C_{ts\lambda}^{ij} - C_{\lambda}^j) \quad (14)$$

So total transshipment cost from retailer  $i$  to  $j$  is:

$$C_{TS\lambda}^{ij} = \sum_{i=1}^n \sum_{j=1, i \neq j}^k \sum_{\lambda=1}^m \hat{C}_{ts\lambda}^{ij} Q_{(LTS)\lambda}^{ij} \quad (15)$$

m) Total cost without transshipment is taken as the sum of holding and stock-out cost (Quesada-Pineda, 2010) described below:

$$C_2 = \sum_{i=1}^n \sum_{\lambda=1}^m c_{h\lambda}^i Q_{h\lambda}^i + \sum_{i=1}^n \sum_{\lambda=1}^m c_{st\lambda}^i Q_{st\lambda}^i \quad (16)$$

$C_2$ , represents the total cost without transshipment.

n) Total cost per period, with transshipment can be represented as the sum of holding, shortage and effective lateral transshipment cost (Herer et al., 2006). It can be given by the following relationship:

$$C_1 = \sum_{i=1}^n \sum_{\lambda=1}^m c_{h\lambda}^i Q_{h\lambda}^i + \sum_{i=1}^n \sum_{\lambda=1}^m c_{st\lambda}^i Q_{st\lambda}^i + \sum_{i=1}^n \sum_{j=1, i \neq j}^k \sum_{\lambda=1}^m \hat{C}_{ts\lambda}^{ij} Q_{(LTS)\lambda}^{ij} \quad (17)$$

In this work the two costs  $C_1$  and  $C_2$  given by equations (16) and (17) are to be compared for every period including the whole system. Here the ordering cost measurement is excluded to make high frequency ordering feasible.

The performance of the system is analyzed on the basis of aforementioned costs and service levels which are the performance measurements set by the management closely linking the customer services. Service levels can be described in two ways demonstrated by demand service level and period service level depicting the contended customers (Sidola, 2004, Thomopoulos, 2004).

Demand service level can be mathematically written as:

$$D_{SL} = \frac{\sum_{i=1}^n \mu_{ds\lambda}^i}{\sum_{i=1}^n \mu_{T\lambda}^i} \quad (18)$$

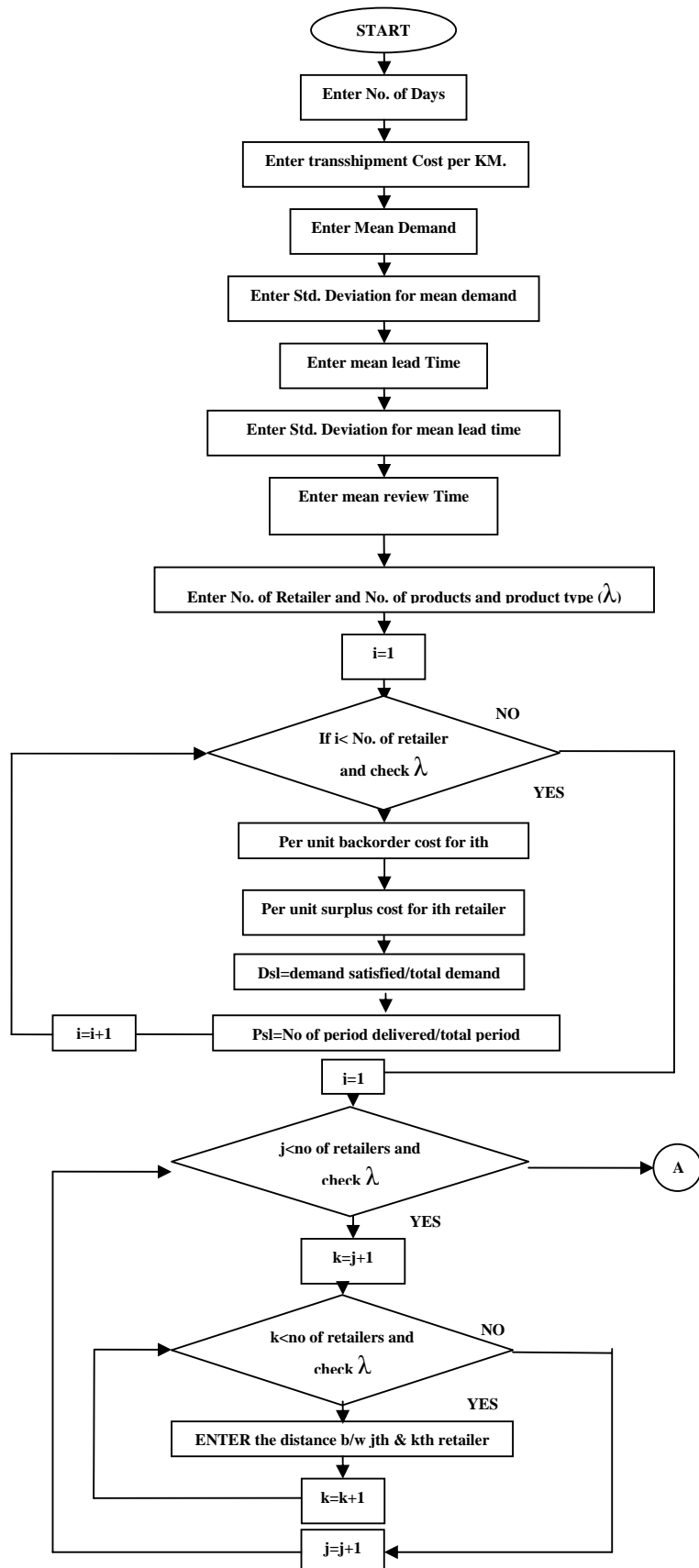
where  $\sum_{i=1}^n \mu_{ds\lambda}^i$ ,  $\sum_{i=1}^n \mu_{T\lambda}^i$  represents the demand satisfied by retailer  $i$  for  $\lambda$  products and total demand arrived respectively.

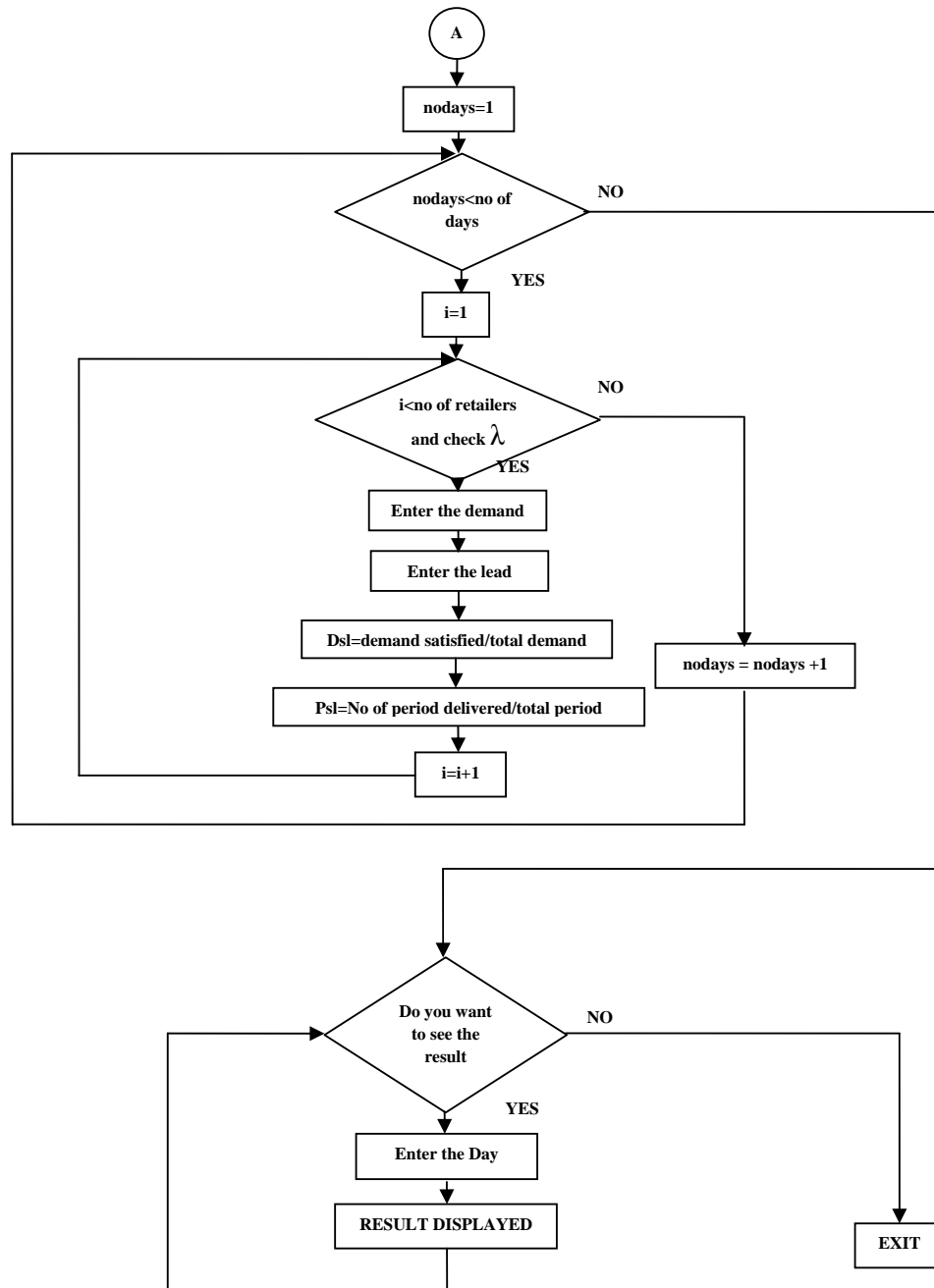
o) Period service level can be written as follows:

$$P_{SL} = N_{D\lambda}^i / N_{T\lambda}^i \quad (19)$$

$N_{D\lambda}^i$  and  $N_{T\lambda}^i$  are the delivery periods and total periods for retailer  $i$  for  $\lambda$  products.

Above mentioned formulated model is used to develop an in-house program in C++. Programming is done in such a way that if a retailer faces shortage, will transship the material from the nearest retailer having surplus and so on. Inputs to the program are the in-hand inventory, demand faced by the retailers, respective lead-times, holding, stock-out and effective transshipment costs. Outputs are received in terms of inventory reached at particular day, surplus quantities, stock-out quantities, service levels and respective costs faced by each retailer. Based upon the formulated model the flow chart is represented by figure 3.1.





**Figure 3.1 Flow chart for the model formulated.**

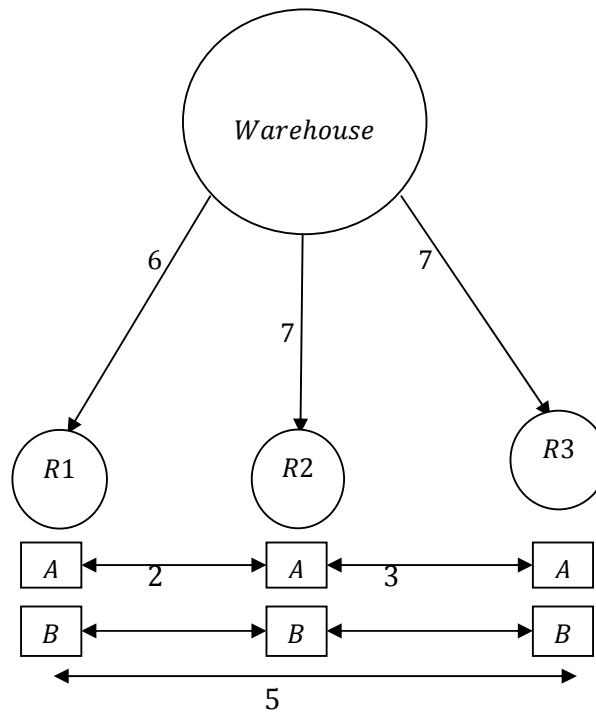
An illustrative example is considered for model verification and for its evaluation as explained in the upcoming section.

### 3.3 EXAMPLE PROBLEM

For the verification and evaluation of the formulated model and the in-house program an example problem has been solved. On the basis of results obtained from this example problem the same program will be implemented on the case studies that have been done on three Indian based automobile industries. The example problem covers the self generated data that includes three retail outlets ( $R_1$ ,  $R_2$  and  $R_3$ ) with two different products (A and B), and these retailers are catered by single central warehouse. Warehouse is far away from retail outlets, but retailers are at moderate distance with each other. Therefore, strategy related to transshipment of the inventory across different retailers should be effective in minimizing the loss due to passage of time. Since retail outlets have variable demand and lead-time, which are randomly generated, they face shortage or surplus. However with lateral transshipment both holding and shortage quantity decreases simultaneously, thereby reducing the total expected cost. If the retail outlets do not consider for lateral transshipment, they have to pay holding cost for surplus inventory that remains after the individual demand is satisfied and have to pay for shortage cost, if stock-out take place. In this example problem three outlets have been considered to form a complete pooling group. Complete pooling means that outlet with surplus will transship, its entire inventory to fulfill the shortage at the other outlets if the surplus is less than or equal to the shortage. In the following section we will discuss the data set and the solution steps to solve the illustrative example.

For three retailers, the demand and lead-time of the two products have been randomly generated as given in table 3.1. The cost details are as follows:

- Holding cost/ day for product 1 and 2 are Rs. 3 and 4 respectively.
- Stock-out cost/ unit for the same products are Rs. 5 and 7 respectively.
- Lateral transshipment cost/ unit is elaborated in figure. 3.2 below:



**Figure 3.2 Transshipment cost from central warehouse and between retailers.**

In the above figure the lateral transshipment cost per unit between first and second retailer is Rs. 2, between second and third retailer is Rs. 3 and between first and third retailer is Rs. 5. Transshipment cost from central warehouse to retailers is Rs. 6, 7 and 7 respectively. Example problem is solved for lateral transshipment as well as without lateral transshipment.

**Table 3.1 Expected demand and lead-time.**

| Periods | $\mu D_{11}$ | $TL_{11}$ | $\mu D_{12}$ | $TL_{12}$ | $\mu D_{21}$ | $TL_{21}$ | $\mu D_{22}$ | $TL_{22}$ | $\mu D_{31}$ | $TL_{31}$ | $\mu D_{32}$ | $TL_{32}$ |
|---------|--------------|-----------|--------------|-----------|--------------|-----------|--------------|-----------|--------------|-----------|--------------|-----------|
| 1       | 10           | 2         | 12           | 2         | 8            | 2         | 14           | 2         | 16           | 3         | 22           | 3         |
| 2       | 18           | 4         | 19           | 4         | 12           | 3         | 16           | 3         | 12           | 3         | 12           | 3         |
| 3       | 6            | 3         | 8            | 3         | 8            | 3         | 10           | 3         | 6            | 2         | 16           | 2         |
| 4       | 20           | 4         | 18           | 3         | 16           | 3         | 18           | 4         | 22           | 4         | 15           | 3         |
| 5       | 18           | 3         | 22           | 2         | 21           | 4         | 3            | 4         | 15           | 3         | 10           | 4         |
| 6       | 14           | 3         | 16           | 4         | 10           | 3         | 22           | 3         | 20           | 3         | 14           | 4         |
| 7       | 15           | 3         | 13           | 5         | 16           | 3         | 15           | 4         | 11           | 2         | 16           | 3         |
| 8       | 10           | 2         | 16           | 4         | 10           | 4         | 19           | 3         | 14           | 3         | 20           | 3         |
| 9       | 12           | 2         | 15           | 4         | 15           | 3         | 17           | 5         | 18           | 3         | 12           | 4         |
| 10      | 10           | 3         | 6            | 4         | 12           | 4         | 21           | 5         | 15           | 4         | 10           | 4         |
| 11      | 8            | 3         | 21           | 3         | 12           | 5         | 6            | 5         | 16           | 4         | 10           | 5         |
| 12      | 20           | 4         | 8            | 5         | 12           | 5         | 12           | 4         | 15           | 4         | 10           | 5         |
| 13      | 6            | 4         | 16           | 3         | 14           | 4         | 14           | 4         | 8            | 3         | 16           | 4         |
| 14      | 10           | 4         | 9            | 3         | 10           | 4         | 19           | 3         | 6            | 3         | 18           | 4         |
| 15      | 6            | 3         | 14           | 2         | 16           | 3         | 16           | 4         | 10           | 5         | 20           | 4         |
| 16      | 14           | 4         | 17           | 3         | 16           | 3         | 8            | 5         | 17           | 4         | 15           | 3         |
| 17      | 20           | 3         | 3            | 4         | 16           | 4         | 13           | 5         | 8            | 4         | 16           | 3         |
| 18      | 6            | 2         | 15           | 4         | 6            | 3         | 14           | 4         | 16           | 3         | 10           | 5         |
| 19      | 15           | 3         | 11           | 3         | 10           | 2         | 16           | 3         | 18           | 3         | 12           | 3         |
| 20      | 12           | 2         | 10           | 3         | 10           | 2         | 20           | 3         | 10           | 4         | 10           | 3         |

Considering the mathematical model described above the following procedure has been adopted to solve the present problem:

- First of all mean demand for product A and B is calculated for three retailers using equation no. 3 above.
- Then the mean lead-time has been formulated with the help of equation no. 6 for the same products.
- After calculating the mean lead-time the next step is to solve demand and lead-time variation by using equation no. 4 and 7 respectively.
- Now standard deviation has been found by using equation no. 5.
- At the end, maximum level of inventory and reorder level are to be calculated for all the products with the help of equations no. 1 and 8 respectively.

Table 3.2 gives the observations for related parameters by using the above mentioned formulated model.  $R_{11}$ ,  $R_{21}$ ,  $R_{31}$  represents retailers 1, 2 and 3 containing product A respectively. Similarly  $R_{12}$ ,  $R_{22}$  and  $R_{32}$  signifies second product for the same retailers.

**Table 3.2 Observations for related parameters.**

| Calculations                     | Product A       |                 |                 | Product B       |                 |                 |
|----------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                                  | R <sub>11</sub> | R <sub>21</sub> | R <sub>31</sub> | R <sub>12</sub> | R <sub>22</sub> | R <sub>32</sub> |
| Mean demand                      | 13              | 12              | 14              | 14              | 15              | 15              |
| Mean lead-time                   | 3               | 4               | 3               | 3               | 4               | 4               |
| Standard deviation for demand    | 5               | 4               | 5               | 5               | 5               | 4               |
| Standard deviation for lead-time | 1               | 1               | 1               | 1               | 2               | 2               |
| Demand variation                 | 8-18            | 8-16            | 9-19            | 9-19            | 10-20           | 11-19           |
| Lead-time variation              | 2-4             | 3-5             | 2-4             | 2-4             | 2-6             | 2-6             |
| Max. level of inventory          | 65              | 72              | 84              | 84              | 90              | 90              |
| Reorder level                    | 39              | 36              | 42              | 42              | 60              | 60              |

For the data given in table 3.1, the aforesaid example problem is implemented using the in-house program (appendix – A and B), considering the different equations from 1-19, and comprising the two cases of without transshipment and with transshipment. After obtaining the results in terms of total inventory available, surplus quantities, stock-out quantities etc. it has been analyzed that these particular levels are reduced using transshipment strategy as compared to without transshipment which is detailed in table no. 3.3 to 3.8.

After calculating the holding cost and stock-out cost for the case of without transshipment and transshipment cost including the holding and stock-out cost using transshipment of the products, it has been analyzed that these particular costs and total cost is reduced to a certain extent depicted in table no. 3.9. It has also been shown in the table that the demand service level and period service levels are significantly improved in case of lateral transshipment even having lesser inventories in hand.

**Table 3.3 Total inventory (with and without transshipment) for product 1.**

| Without Transshipment |          |          |          |       | With Transshipment |          |          |       |
|-----------------------|----------|----------|----------|-------|--------------------|----------|----------|-------|
| Periods               | $I_{11}$ | $I_{21}$ | $I_{31}$ | Total | $I_{11}$           | $I_{21}$ | $I_{31}$ | Total |
| 1                     | 65       | 72       | 84       | 221   | 65                 | 72       | 84       | 221   |
| 2                     | 55       | 64       | 68       | 187   | 55                 | 64       | 68       | 187   |
| 3                     | 37       | 52       | 56       | 145   | 37                 | 52       | 56       | 145   |
| 4                     | 31       | 44       | 50       | 125   | 31                 | 44       | 50       | 125   |
| 5                     | 11       | 28       | 28       | 67    | 11                 | 28       | 28       | 67    |
| 6                     | 0        | 7        | 13       | 20    | 0                  | 0        | 13       | 13    |
| 7                     | 34       | 0        | 0        | 34    | 28                 | 6        | 0        | 34    |
| 8                     | 19       | 44       | 0        | 63    | 0                  | 44       | 0        | 44    |
| 9                     | 40       | 34       | 71       | 145   | 31                 | 10       | 71       | 112   |
| 10                    | 28       | 47       | 66       | 141   | 14                 | 28       | 66       | 108   |
| 11                    | 43       | 35       | 51       | 129   | 38                 | 16       | 51       | 105   |
| 12                    | 47       | 23       | 35       | 105   | 47                 | 4        | 35       | 86    |
| 13                    | 27       | 36       | 20       | 83    | 19                 | 44       | 20       | 83    |
| 14                    | 31       | 22       | 12       | 65    | 25                 | 30       | 12       | 67    |
| 15                    | 29       | 24       | 6        | 59    | 23                 | 32       | 6        | 61    |
| 16                    | 23       | 8        | 49       | 80    | 17                 | 12       | 49       | 78    |
| 17                    | 29       | 14       | 55       | 98    | 28                 | 12       | 54       | 94    |
| 18                    | 15       | 28       | 47       | 90    | 8                  | 18       | 52       | 78    |
| 19                    | 25       | 48       | 31       | 104   | 18                 | 42       | 36       | 96    |
| 20                    | 10       | 48       | 13       | 71    | 3                  | 32       | 36       | 71    |

**Table 3.4 Total inventory (with and without transshipment) for product 2.**

| Without Transshipment |          |          |          |       | With Transshipment |          |          |       |
|-----------------------|----------|----------|----------|-------|--------------------|----------|----------|-------|
| Periods               | $I_{12}$ | $I_{22}$ | $I_{32}$ | Total | $I_{12}$           | $I_{22}$ | $I_{32}$ | Total |
| 1                     | 84       | 90       | 90       | 264   | 84                 | 90       | 90       | 264   |
| 2                     | 72       | 76       | 68       | 216   | 72                 | 76       | 68       | 216   |
| 3                     | 53       | 60       | 56       | 169   | 53                 | 60       | 56       | 169   |
| 4                     | 45       | 50       | 40       | 135   | 45                 | 50       | 40       | 135   |
| 5                     | 27       | 32       | 25       | 84    | 27                 | 32       | 25       | 84    |
| 6                     | 5        | 59       | 65       | 129   | 5                  | 59       | 65       | 129   |
| 7                     | 0        | 47       | 51       | 98    | 0                  | 36       | 51       | 91    |
| 8                     | 79       | 32       | 50       | 161   | 79                 | 21       | 50       | 150   |
| 9                     | 63       | 31       | 30       | 124   | 63                 | 20       | 30       | 113   |
| 10                    | 48       | 39       | 28       | 115   | 48                 | 39       | 28       | 115   |
| 11                    | 47       | 18       | 48       | 113   | 47                 | 18       | 48       | 113   |
| 12                    | 26       | 46       | 58       | 130   | 26                 | 46       | 58       | 130   |
| 13                    | 0        | 34       | 48       | 82    | 0                  | 32       | 48       | 80    |
| 14                    | 0        | 20       | 44       | 64    | 0                  | 2        | 44       | 46    |
| 15                    | 58       | 17       | 36       | 111   | 58                 | 17       | 10       | 85    |
| 16                    | 44       | 21       | 16       | 81    | 31                 | 21       | 0        | 52    |
| 17                    | 27       | 31       | 10       | 68    | 8                  | 20       | 10       | 38    |
| 18                    | 50       | 52       | 26       | 128   | 58                 | 32       | 26       | 116   |
| 19                    | 35       | 38       | 34       | 107   | 43                 | 18       | 60       | 121   |
| 20                    | 54       | 22       | 40       | 116   | 55                 | 19       | 58       | 132   |

**Table 3.5 Surplus inventory (with and without transshipment) for product 1.**

| Without Transshipment |          |          |          |       | With Transshipment |          |          |       |
|-----------------------|----------|----------|----------|-------|--------------------|----------|----------|-------|
| Periods               | $I_{11}$ | $I_{21}$ | $I_{31}$ | Total | $I_{11}$           | $I_{21}$ | $I_{31}$ | Total |
| 1                     | 55       | 64       | 68       | 187   | 55                 | 64       | 68       | 187   |
| 2                     | 37       | 52       | 56       | 145   | 37                 | 52       | 56       | 145   |
| 3                     | 31       | 44       | 50       | 125   | 31                 | 44       | 50       | 125   |
| 4                     | 11       | 28       | 28       | 67    | 11                 | 28       | 28       | 67    |
| 5                     | 0        | 7        | 13       | 20    | 0                  | 0        | 13       | 13    |
| 6                     | 0        | 0        | 0        | 0     | 0                  | 0        | 0        | 0     |
| 7                     | 19       | 0        | 0        | 19    | 0                  | 0        | 0        | 0     |
| 8                     | 9        | 34       | 0        | 43    | 0                  | 10       | 0        | 10    |
| 9                     | 28       | 19       | 53       | 100   | 14                 | 0        | 53       | 67    |
| 10                    | 18       | 35       | 51       | 104   | 4                  | 16       | 51       | 71    |
| 11                    | 35       | 23       | 35       | 93    | 30                 | 4        | 35       | 69    |
| 12                    | 27       | 11       | 20       | 58    | 19                 | 0        | 20       | 39    |
| 13                    | 21       | 22       | 12       | 55    | 15                 | 30       | 12       | 57    |
| 14                    | 21       | 12       | 6        | 39    | 15                 | 20       | 6        | 35    |
| 15                    | 23       | 8        | 0        | 31    | 17                 | 12       | 0        | 29    |
| 16                    | 9        | 0        | 32       | 41    | 0                  | 0        | 31       | 31    |
| 17                    | 9        | 0        | 47       | 56    | 4                  | 0        | 46       | 50    |
| 18                    | 9        | 22       | 31       | 62    | 2                  | 12       | 36       | 50    |
| 19                    | 10       | 38       | 13       | 61    | 3                  | 32       | 18       | 53    |
| 20                    | 0        | 38       | 3        | 41    | 0                  | 13       | 26       | 39    |

**Table 3.6 Surplus inventory (with and without transshipment) for product 2.**

| Without Transshipment |          |          |          |       | With Transshipment |          |          |       |
|-----------------------|----------|----------|----------|-------|--------------------|----------|----------|-------|
| Periods               | $I_{12}$ | $I_{22}$ | $I_{32}$ | Total | $I_{12}$           | $I_{22}$ | $I_{32}$ | Total |
| 1                     | 72       | 76       | 68       | 216   | 72                 | 76       | 68       | 216   |
| 2                     | 53       | 60       | 56       | 169   | 53                 | 60       | 56       | 169   |
| 3                     | 45       | 50       | 40       | 135   | 45                 | 50       | 40       | 135   |
| 4                     | 27       | 32       | 25       | 84    | 27                 | 32       | 25       | 84    |
| 5                     | 5        | 29       | 15       | 49    | 5                  | 29       | 15       | 49    |
| 6                     | 0        | 37       | 51       | 88    | 0                  | 26       | 51       | 77    |
| 7                     | 0        | 32       | 35       | 67    | 0                  | 0        | 35       | 35    |
| 8                     | 63       | 13       | 30       | 106   | 63                 | 2        | 30       | 95    |
| 9                     | 48       | 14       | 18       | 80    | 48                 | 3        | 18       | 69    |
| 10                    | 42       | 18       | 18       | 78    | 42                 | 18       | 18       | 78    |
| 11                    | 26       | 12       | 38       | 76    | 26                 | 12       | 38       | 76    |
| 12                    | 0        | 34       | 48       | 82    | 0                  | 32       | 48       | 80    |
| 13                    | 0        | 20       | 32       | 52    | 0                  | 2        | 32       | 34    |
| 14                    | 0        | 0        | 26       | 26    | 0                  | 0        | 0        | 0     |
| 15                    | 44       | 0        | 16       | 60    | 31                 | 0        | 0        | 31    |
| 16                    | 27       | 13       | 0        | 40    | 8                  | 0        | 0        | 8     |
| 17                    | 24       | 18       | 0        | 42    | 5                  | 0        | 0        | 5     |
| 18                    | 35       | 38       | 16       | 89    | 43                 | 18       | 16       | 77    |
| 19                    | 24       | 22       | 22       | 68    | 32                 | 2        | 48       | 82    |
| 20                    | 44       | 2        | 30       | 76    | 44                 | 0        | 48       | 92    |

**Table 3.7 Stock-out quantities (with and without transshipment) for product 1.**

| Periods | Without Transshipment |                 |                 |       | With Transshipment |                 |                 |       |
|---------|-----------------------|-----------------|-----------------|-------|--------------------|-----------------|-----------------|-------|
|         | S <sub>01</sub>       | S <sub>02</sub> | S <sub>03</sub> | Total | S <sub>01</sub>    | S <sub>02</sub> | S <sub>03</sub> | Total |
| 1       | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 2       | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 3       | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 4       | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 5       | 7                     | 0               | 0               | 7     | 0                  | 0               | 0               | 0     |
| 6       | 14                    | 3               | 7               | 24    | 14                 | 10              | 7               | 31    |
| 7       | 0                     | 16              | 11              | 27    | 0                  | 0               | 8               | 8     |
| 8       | 0                     | 0               | 14              | 14    | 0                  | 0               | 0               | 0     |
| 9       | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 10      | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 11      | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 12      | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 13      | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 14      | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 15      | 0                     | 0               | 4               | 04    | 0                  | 0               | 0               | 0     |
| 16      | 0                     | 8               | 0               | 8     | 0                  | 0               | 0               | 0     |
| 17      | 0                     | 2               | 0               | 2     | 0                  | 0               | 0               | 0     |
| 18      | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 19      | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 20      | 2                     | 0               | 0               | 2     | 0                  | 0               | 0               | 0     |

**Table 3.8 Stock-out quantities (with and without transshipment) for product 2.**

| Periods | Without Transshipment |                 |                 |       | With Transshipment |                 |                 |       |
|---------|-----------------------|-----------------|-----------------|-------|--------------------|-----------------|-----------------|-------|
|         | S <sub>01</sub>       | S <sub>02</sub> | S <sub>03</sub> | Total | S <sub>01</sub>    | S <sub>02</sub> | S <sub>03</sub> | Total |
| 1       | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 2       | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 3       | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 4       | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 5       | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 6       | 11                    | 0               | 0               | 11    | 0                  | 0               | 0               | 0     |
| 7       | 13                    | 0               | 0               | 13    | 0                  | 0               | 0               | 0     |
| 8       | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 9       | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 10      | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 11      | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 12      | 2                     | 0               | 0               | 2     | 0                  | 0               | 0               | 0     |
| 13      | 16                    | 0               | 0               | 16    | 0                  | 0               | 0               | 0     |
| 14      | 9                     | 2               | 0               | 11    | 3                  | 0               | 0               | 3     |
| 15      | 0                     | 3               | 0               | 3     | 0                  | 0               | 0               | 0     |
| 16      | 0                     | 0               | 3               | 3     | 0                  | 0               | 0               | 0     |
| 17      | 0                     | 0               | 6               | 6     | 0                  | 0               | 0               | 0     |
| 18      | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 19      | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |
| 20      | 0                     | 0               | 0               | 0     | 0                  | 0               | 0               | 0     |

**Table 3.9 Comparison of costs and service levels (with and without transshipment).**

| Costs                    | Product A             |                 |                 |                    |                 |                 | Product B             |                 |                 |                    |                 |                 |
|--------------------------|-----------------------|-----------------|-----------------|--------------------|-----------------|-----------------|-----------------------|-----------------|-----------------|--------------------|-----------------|-----------------|
|                          | Without transshipment |                 |                 | With transshipment |                 |                 | Without transshipment |                 |                 | With transshipment |                 |                 |
|                          | R <sub>11</sub>       | R <sub>21</sub> | R <sub>31</sub> | R <sub>11</sub>    | R <sub>21</sub> | R <sub>31</sub> | R <sub>12</sub>       | R <sub>22</sub> | R <sub>32</sub> | R <sub>12</sub>    | R <sub>22</sub> | R <sub>32</sub> |
| Holding cost (Rs.)       | 1116                  | 1371            | 1554            | 771                | 1011            | 1647            | 2316                  | 2080            | 2336            | 2176               | 1448            | 2344            |
| Stock-out cost (Rs.)     | 115                   | 145             | 180             | 70                 | 50              | 75              | 357                   | 35              | 63              | 21                 | 0               | 0               |
| Transshipment cost (Rs.) | 0                     | 0               | 0               | 78                 | 33              | 66              | 0                     | 0               | 0               | 162                | 74              | 121             |
| Total cost (Rs.)         | 1231                  | 1516            | 1734            | 919                | 1094            | 1788            | 2673                  | 2115            | 2399            | 2359               | 1522            | 2465            |
| Demand service level     | 0.91                  | 0.88            | 0.87            | 0.95               | 0.96            | 0.94            | 0.81                  | 0.98            | 0.97            | 0.99               | 1.0             | 1.0             |
| Period service level     | 0.85                  | 0.80            | 0.80            | 0.95               | 0.95            | 0.90            | 0.75                  | 0.90            | 0.90            | 0.95               | 1.0             | 1.0             |

On the basis of the results obtained we have evaluated and verified the developed model and program and it has been observed that all parameters like total inventory available, surplus quantities, stock-out quantities and total expected cost in majority of the periods reduces and service levels have been enhanced while implementing lateral transshipment. So lateral transshipment is an effective tool to minimize inventory, reduces costs and improves the service levels. The above model has been implemented on three case studies based on Indian automobile industries as explained in next chapters.

### CASE STUDY - 1

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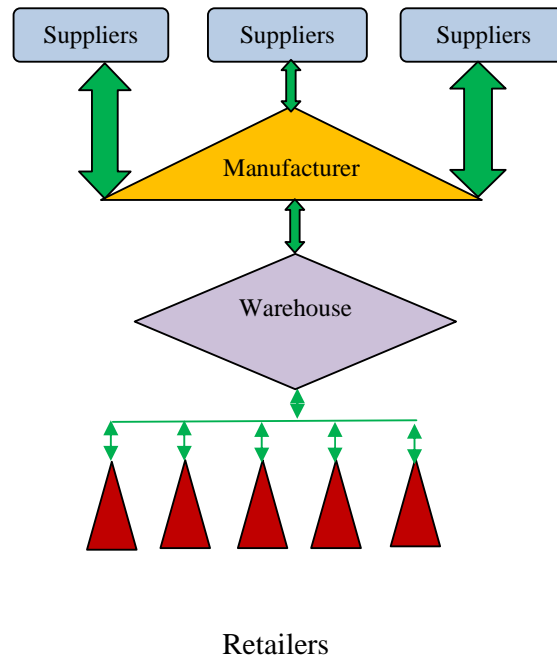
#### 4.1 MARUTI SUZUKI INDIA LIMITED (MSIL)

Maruti Suzuki India Limited (formerly Maruti Udyog Limited), a subsidiary of Suzuki Motor Corporation of Japan, is India's largest passenger car company, accounting for over 50 per cent of the domestic car market. Maruti Udyog Limited (MUL), established in 1981, had a prime objective to meet the growing demand of a personal mode of transport, which is caused due to lack of efficient public transport system. A license and a joint venture agreement were signed between Government of India and Suzuki Motor Company (now Suzuki Motor Corporation of Japan) in Oct 1982. The objectives of MSIL cover modernization of the Indian automobile industry, production of fuel efficient vehicles to conserve scarce resources and production of large number of motor vehicles which is necessary for economic growth. In 2001, MUL became one of the first automobile companies, globally, to be honored with an ISO 9000:2000 certificate. The production/ R&D are spread across 297 acres with 3 fully-integrated production facilities. As of 31<sup>st</sup> March, 2011, the company has a sales network of 933 outlets in 666 towns and cities and provides maintenance support to customers at 2946 workshops in over 1395 towns and cities in the country having inventory of items at a distribution center (DC) located in North India (<http://www.marutisuzuki.com>).

SC practices are implemented in MSIL at higher echelons as shown in figure 4.1 but there is no flow of information and material amongst the lower ends (retailers' level). Retailers are not clubbed with each other through any type of transshipments. If a demand occurs at a location and there is no stock on hand, the demand is assumed to be backordered or lost.

In the pull type of inventory management system that is proposed in this work, where a demand is being generated by the retailers having zero inventory, lateral transshipment between the retailers may be allowed. Also in the present distribution

structure the retailers are apart by moderate distances, so transshipment may done by road and by the car itself and the cars can be delivered on the same day.

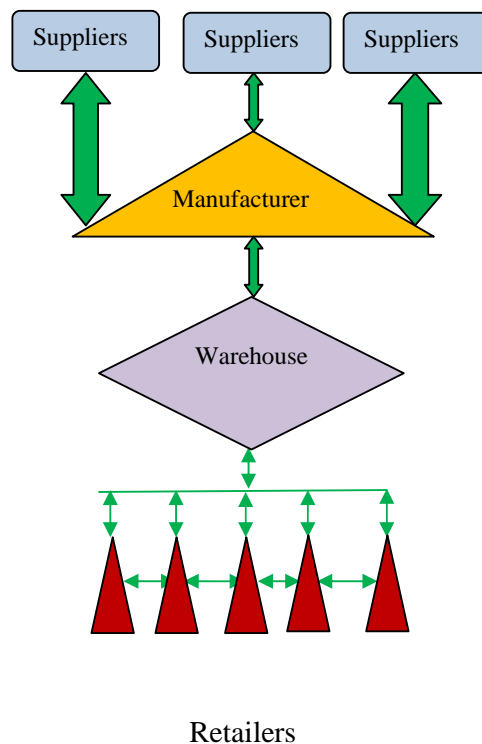


**Figure 4.1 Investigated supply chain structure.**

## 4.2 DATA COLLECTION

Data has been collected from three retailers [Retailer-1-Bhiwani (B), retailer-2-Rohtak (R), retailer-3-Sonepat (S)] spanning the months of January-April, 2009 for a particular brand, Wagon – R Duo, covering 360 demand periods deliberated as 120/retailer. Collected data accommodates the day wise demand confronted by the retailers, daily opening stock at retailers' end and lead-time in getting the products from central warehouse. Holding cost/car/day is Rs. 118/-, stock-out cost/car is Rs. 7500/- individually for the three retailers and transportation cost/car between first and second retailer is Rs. 200/-, between second and third is Rs. 300/- and between first and third is Rs. 500/-. Transshipment cost/car from central warehouse to I, II and III retailer is Rs. 2600/-, 2500/- and 2500/- respectively.

Since retail outlets have variable demand and lead-time, they may face the problem of shortage or surplus of cars. However it has been observed that with lateral transshipment both holding and shortage quantity decreases thereby reducing the total expected cost. If the retail outlets do not go for lateral transshipment, they have to pay the holding cost for surplus inventory once the individual demand is satisfied, or have to pay for shortage cost if stock-out takes place. Figure 4.2 represents the proposed structure in which retailers are grouped together for the sharing of information and material by adopting emergency lateral transshipment policy. The difference in lateral transshipment cost between retailers is due to the variability in their mutual travelling distances. Appendix - C represents the collected data in terms of daily opening stock (In-hand inventory) and their respective demand.



**Figure 4.2 Proposed supply chain structure.**

### 4.3 RESULTS AND DISCUSSIONS

Risk pooling effect, in considered supply chain is evaluated, as per mentioned relationships and mythology in earlier chapters. This supply chain is studied for inventory and related costs. To measure the performance of supply chain, demand service level and period service level are considered. For discussing the different aspects the related graphs have been generated ahead. Various facets of inventory (inventory available per period, surplus quantities and stock out quantities) will be considered, for both the cases, i.e. with transshipment and without transshipment and these aspects are analyzed for individual retailer as well as for the whole system.

Table 4.1 gives the observations for related parameters calculated for different inventory aspects by using formulated model. Appendix-C and table 4.2 represent the available inventory without transshipment and with transshipment respectively. After analyzing the response resulting from the two different strategies, with transshipment as well as without transshipment, it has been concluded that after adopting lateral transshipment, the level of surplus quantities has been affected in the form of reduction by an amount of 30, 62, 80 and 50 for the months of Jan., Feb., Mar. and Apr., 09 respectively in case of first retailer. Similar reducing effects, in surplus quantities, have been observed when this strategy was extended for the remaining retailers during same months as shown in figure 4.3. After having been calculated the data, for holding cost, in effect of the earlier obtained surplus quantities, significant cost reduction was found following the lateral transshipment as given in figure 4.4

Figure 4.5 shows the stock-out quantities of three retailers which have now been reduced in case of lateral transshipment, meeting the demands of more and more customers; moreover the retailers are having lesser inventories in hand, minimizing the holding cost. As the stock-out quantities are reduced, discussed earlier, this effect can be analyzed in terms of decreased stock-out cost which is given in figure 4.6. In figure 4.7 the sum of holding and stock-out cost, and the sum of holding, stock-out and effective transshipment cost have been compared for without and with transshipment respectively, as well as these costs are also shown individually and it has been found that with the incorporation of lateral transshipment, even though the

effective transshipment cost is increasing yet the total cost as well as individual costs are reducing.

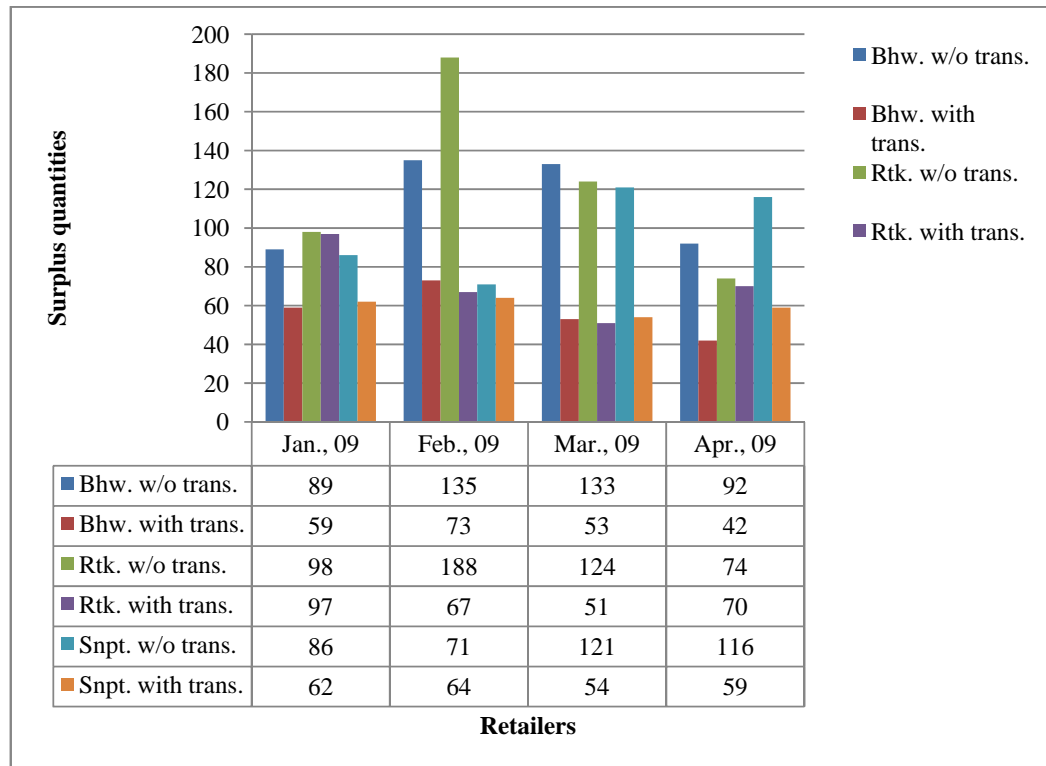
Also with lateral transshipment demand service level and period service level have been enhanced to a considerable amount as shown in table 4.3.

**Table 4.1. Observations for related parameters (MSIL).**

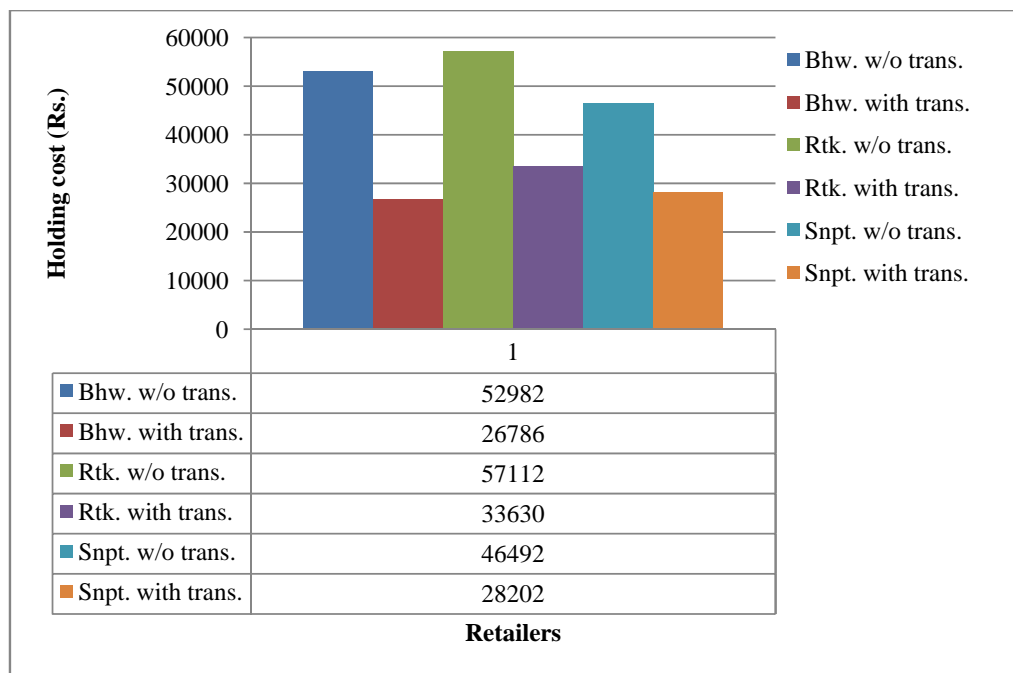
| Calculations<br>Retailers        | Product (Wagon-R Duo) |     |     |
|----------------------------------|-----------------------|-----|-----|
|                                  | B                     | R   | S   |
| Mean demand                      | 1                     | 1   | 1   |
| Mean lead-time                   | 4                     | 4   | 4   |
| Standard deviation for demand    | 1                     | 1   | 1   |
| Standard deviation for lead-time | 1                     | 1   | 1   |
| Demand variation                 | 0-4                   | 0-4 | 0-4 |
| Lead-time variation              | 1-7                   | 1-7 | 1-7 |
| Max. level of inventory          | 6                     | 6   | 6   |
| Reorder level                    | 4                     | 4   | 4   |

**Table 4.2. Total inventory available with transshipment (MSIL).**

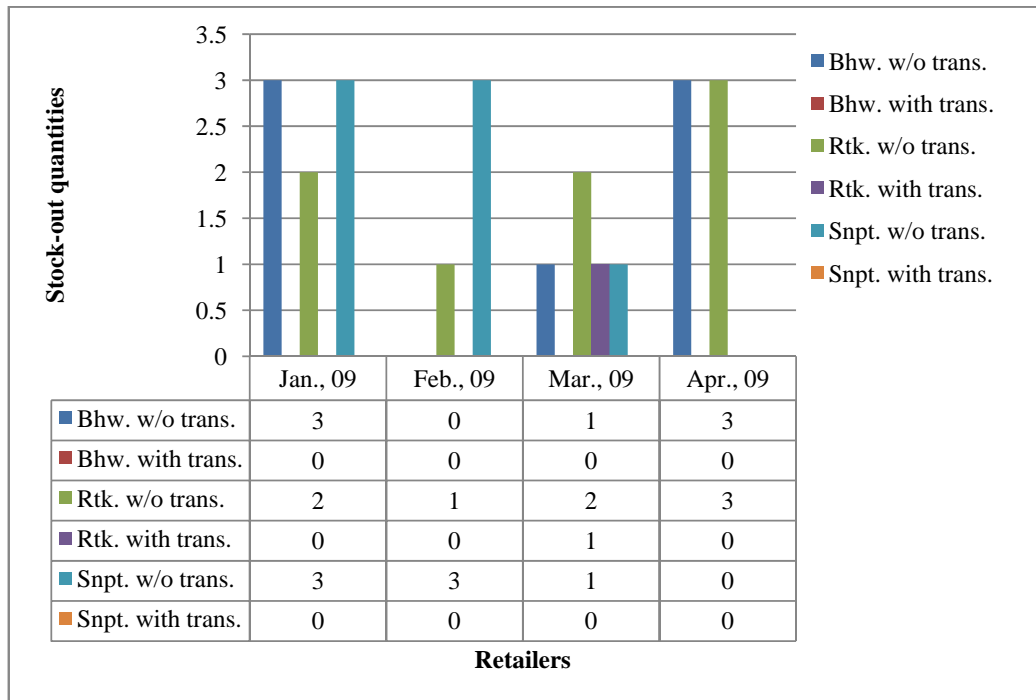
| In-hand Inventory<br>Day | January, 09 |   |   | February, 09 |   |   | March, 09 |   |   | April, 09 |   |   |
|--------------------------|-------------|---|---|--------------|---|---|-----------|---|---|-----------|---|---|
|                          | B           | R | S | B            | R | S | B         | R | S | B         | R | S |
| 1                        | 4           | 0 | 0 | 4            | 3 | 3 | 3         | 5 | 5 | 3         | 4 | 3 |
| 2                        | 3           | 0 | 0 | 4            | 3 | 2 | 1         | 4 | 4 | 2         | 5 | 5 |
| 3                        | 1           | 0 | 6 | 3            | 6 | 3 | 0         | 4 | 3 | 4         | 3 | 4 |
| 4                        | 1           | 6 | 6 | 3            | 6 | 1 | 2         | 4 | 1 | 2         | 2 | 4 |
| 5                        | 1           | 6 | 5 | 3            | 6 | 1 | 2         | 3 | 0 | 0         | 0 | 4 |
| 6                        | 3           | 5 | 5 | 4            | 3 | 0 | 1         | 0 | 0 | 0         | 0 | 3 |
| 7                        | 2           | 4 | 5 | 4            | 3 | 0 | 3         | 2 | 2 | 2         | 0 | 2 |
| 8                        | 2           | 6 | 5 | 4            | 1 | 3 | 1         | 2 | 2 | 0         | 3 | 3 |
| 9                        | 1           | 6 | 4 | 4            | 1 | 3 | 1         | 0 | 4 | 2         | 2 | 2 |
| 10                       | 1           | 5 | 4 | 4            | 1 | 3 | 0         | 0 | 3 | 3         | 4 | 1 |
| 11                       | 1           | 5 | 3 | 5            | 4 | 3 | 2         | 4 | 0 | 1         | 4 | 1 |
| 12                       | 3           | 5 | 3 | 4            | 4 | 3 | 1         | 3 | 0 | 1         | 4 | 3 |
| 13                       | 4           | 4 | 2 | 2            | 5 | 3 | 4         | 2 | 0 | 3         | 4 | 2 |
| 14                       | 4           | 4 | 3 | 2            | 2 | 6 | 3         | 3 | 0 | 2         | 3 | 2 |
| 15                       | 3           | 4 | 1 | 1            | 2 | 5 | 1         | 2 | 3 | 2         | 4 | 2 |
| 16                       | 1           | 4 | 1 | 1            | 0 | 5 | 0         | 2 | 6 | 3         | 4 | 2 |
| 17                       | 1           | 4 | 1 | 2            | 0 | 3 | 2         | 0 | 3 | 1         | 2 | 2 |
| 18                       | 3           | 5 | 3 | 4            | 0 | 1 | 2         | 2 | 1 | 1         | 2 | 2 |
| 19                       | 3           | 5 | 2 | 1            | 4 | 1 | 1         | 2 | 1 | 0         | 2 | 1 |
| 20                       | 1           | 4 | 4 | 1            | 4 | 1 | 4         | 3 | 1 | 0         | 4 | 3 |
| 21                       | 3           | 2 | 4 | 0            | 5 | 1 | 4         | 1 | 0 | 3         | 2 | 2 |
| 22                       | 3           | 2 | 4 | 2            | 4 | 3 | 3         | 2 | 3 | 4         | 3 | 2 |
| 23                       | 2           | 2 | 2 | 2            | 3 | 4 | 3         | 0 | 4 | 4         | 2 | 3 |
| 24                       | 0           | 0 | 2 | 5            | 2 | 4 | 5         | 0 | 4 | 3         | 2 | 2 |
| 25                       | 2           | 2 | 4 | 5            | 2 | 4 | 4         | 0 | 3 | 3         | 2 | 2 |
| 26                       | 2           | 4 | 4 | 5            | 2 | 4 | 4         | 3 | 3 | 2         | 3 | 4 |
| 27                       | 2           | 4 | 3 | 4            | 4 | 4 | 3         | 3 | 3 | 4         | 3 | 2 |
| 28                       | 4           | 3 | 5 | 4            | 3 | 6 | 3         | 4 | 4 | 3         | 5 | 2 |
| 29                       | 6           | 3 | 3 |              |   |   | 2         | 4 | 4 | 3         | 5 | 3 |
| 30                       | 6           | 3 | 3 |              |   |   | 4         | 4 | 4 | 2         | 5 | 2 |
| 31                       | 6           | 3 | 3 |              |   |   | 3         | 4 | 3 |           |   |   |



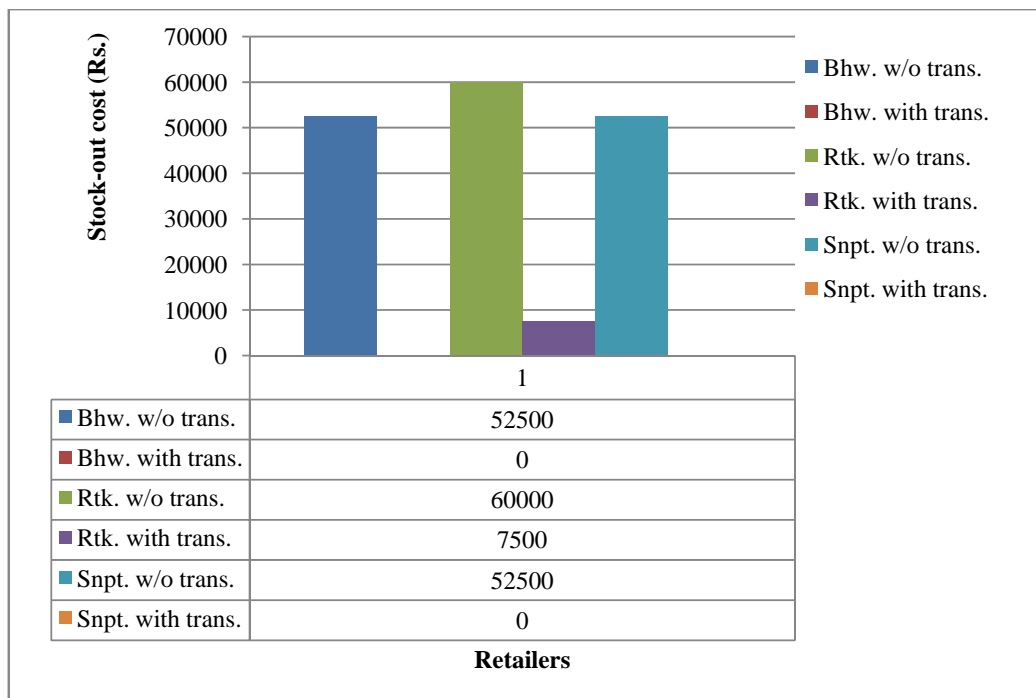
**Figure 4.3 Surplus quantities with and without transshipment (MSIL).**



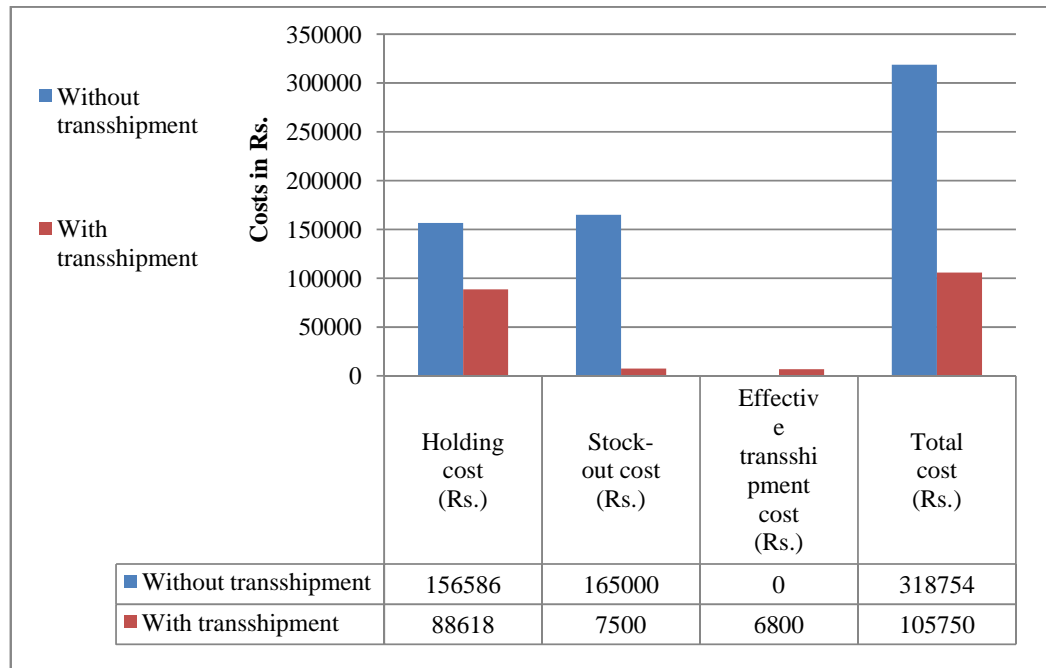
**Figure 4.4 Holding cost with and without transshipment (MSIL).**



**Figure 4.5 Stock-out quantities with and without transshipment (MSIL).**



**Figure 4.6 Stock-out cost with and without transshipment (MSIL).**



**Figure 4.7 Comparison of holding, stock-out, effective transshipment and total cost with and without transshipment (MSIL).**

**Table 4.3 Service levels with and without transshipment (MSIL).**

| Retailers | Demand service level      |                        | Period service level      |                        |
|-----------|---------------------------|------------------------|---------------------------|------------------------|
|           | Without transshipment (%) | With transshipment (%) | Without transshipment (%) | With transshipment (%) |
| Bhiwani   | 90                        | 100                    | 94                        | 100                    |
| Rohtak    | 89                        | 99                     | 93                        | 99                     |
| Sonepat   | 89                        | 100                    | 94                        | 100                    |

### CASE STUDY - 2

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#### 5.1 BAJAJ AUTO LIMITED (BAL)

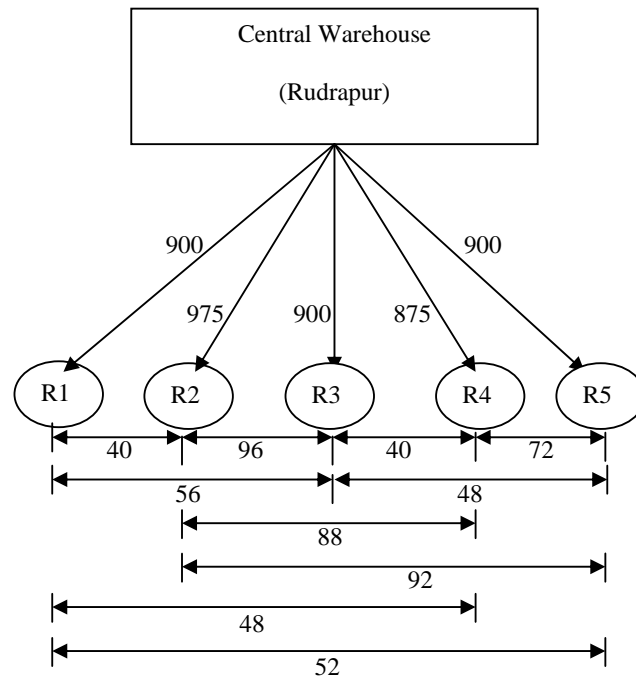
The Bajaj group is amongst the top 10 business houses in India. Its footprint stretches over an extensive range of industries, spanning automobiles (two-wheelers and three-wheelers), home appliances, lighting, iron and steel, insurance, travel and finance. The group's flagship company, Bajaj Auto Limited, is ranked as the world's fourth largest and India's second largest two- and three- wheeler manufacturer and the Bajaj brand is well-known across a number of countries in Latin America, Africa, Middle East, South and South East Asia. Bajaj Auto limited is one of the most admired names in the two and three-wheelers sectors. It has a sales network of 498 outlets, and provides maintenance support to clientele at 1500 workshops. Beside this company have 1400 rural outlets in towns with population of 25000 and below.

Inspiring poise, the tagline, has built up confidence, through excellent engineering, not only to familial consumers but also globally. The strength of the company is its eminence products, brilliance in engineering and design, and its ability to delight the customers. BAL is dedicated to avoidance of pollution, continual improvement of environment performance and compliance with all environmental legislation and regulations. They always believe in providing the customer 'value for money' and keep a special eye upon eminence, safety, productivity, cost and delivery. Figure 4.1 represents the present structure of the supply chain network in the business in which retailers themselves don't contribute into any type of material and information transfer. Figure 4.2 represents the proposed structure of the supply chain management in BAL. In this proposed structure emergency lateral transshipment approach is used to link retailers with each other so that they can share their inventory in case when anyone of them faces a stock-out.

## 5.2 DATA COLLECTION

For the brand Platina-125 (two-wheeler) of Bajaj Auto Ltd., the data for daily opening stock and demand per day reaching to the five retailers [R1-Jind (J), R2-Kaithal (K), R3-Bhiwani (B), R4-Rohtak (R), R5-Hissar (H)], has been collected for the months of January 2009 to June 2009 as shown in appendix-D.

Holding cost/vehicle/day is Rs. 12/-, stock-out cost/vehicle is Rs. 900/- separately for five retailers. Transshipment cost from central warehouse to respective retailers and lateral transshipment cost amongst the retailers (in Rs/-) is represented by the line diagram shown in figure 5.1 below.



**Figure 5.1 Transshipment cost from central warehouse and between retailers (BAL).**

### 5.3 RESULTS AND DISCUSSIONS

Table 5.1 gives the observations for related parameters. Table 5.2 represents the total inventory available with transshipment for different retailers like Jind, Kaithal, Bhiwani etc. whereas the total inventory available without transshipment is given ahead in appendix-D. It has been observed that retailers are left with lesser inventories while doing transshipment amongst them. Figure 5.2 to 5.6 represent surplus quantities, holding cost, stock-out quantities, stock-out cost and a comparison of total cost, with and without transshipment for all the retailers respectively and table 5.3 shows improvements in service levels in a similar way as was adopted in the previous case study.

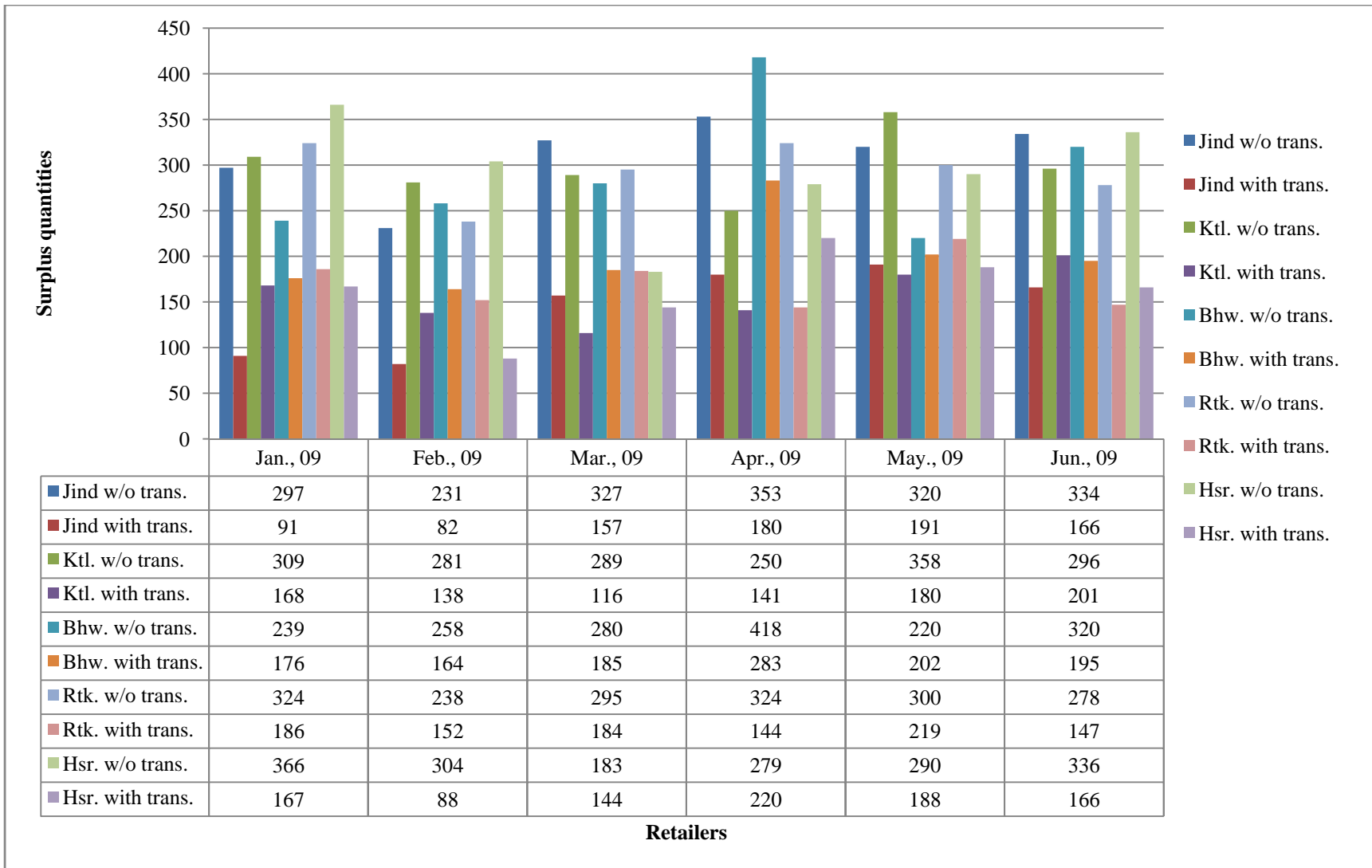
Results give us an insight that emergency lateral transshipment approach reduces inventory, surplus quantities, undelivered customers and all the associated costs in an organization as well as increases the service levels.

**Table 5.1 Observations for related parameters (BAL).**

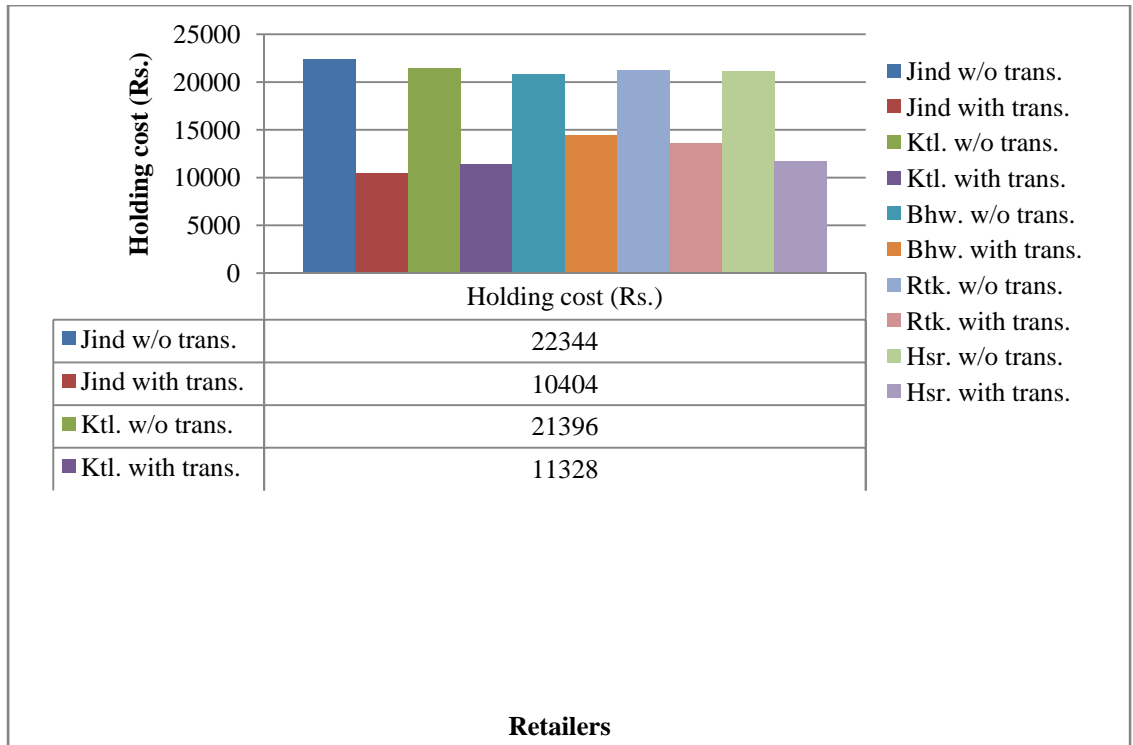
| Calculations                     | Product (Platina-125) |      |      |      |      |
|----------------------------------|-----------------------|------|------|------|------|
|                                  | J                     | K    | B    | R    | H    |
| Mean demand                      | 2                     | 2    | 2    | 2    | 2    |
| Mean lead-time                   | 4                     | 4    | 4    | 4    | 4    |
| Standard deviation for demand    | 2                     | 2    | 2    | 2    | 2    |
| Standard deviation for lead-time | 2                     | 2    | 2    | 2    | 2    |
| Demand variation                 | 0-8                   | 0-8  | 0-8  | 0-8  | 0-8  |
| Lead-time variation              | 0-10                  | 0-10 | 0-10 | 0-10 | 0-10 |
| Max. level of inventory          | 14                    | 14   | 14   | 14   | 14   |
| Reorder level                    | 8                     | 8    | 8    | 8    | 8    |

**Table 5.2 Total inventory available with transshipment (BAL).**

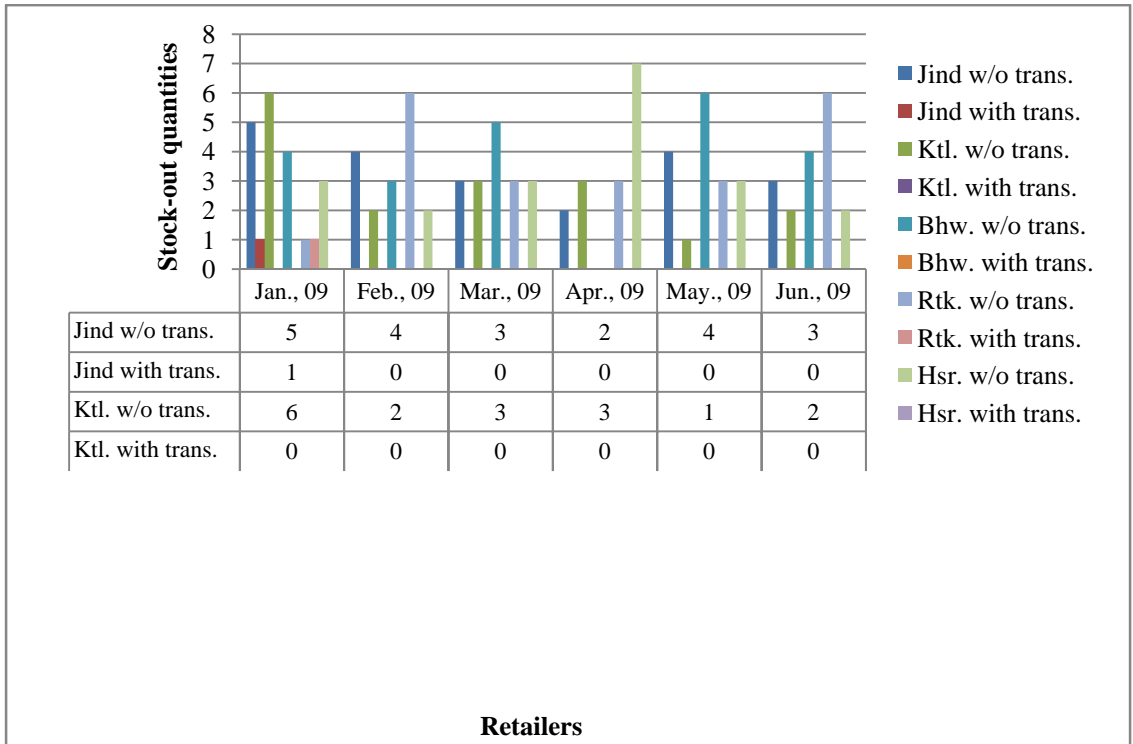
| In-hand inventory | January, 09 |    |    |    |    | February, 09 |    |    |    |    | March, 09 |    |    |    |   | April, 09 |    |    |    |    | May, 09 |    |    |    |    | June, 09 |    |    |    |    |
|-------------------|-------------|----|----|----|----|--------------|----|----|----|----|-----------|----|----|----|---|-----------|----|----|----|----|---------|----|----|----|----|----------|----|----|----|----|
|                   | Day         | J  | K  | B  | R  | H            | J  | K  | B  | R  | H         | J  | K  | B  | R | H         | J  | K  | B  | R  | H       | J  | K  | B  | R  | H        | J  | K  | B  | R  |
| 1                 | 12          | 14 | 8  | 14 | 10 | 9            | 3  | 11 | 8  | 10 | 3         | 7  | 5  | 9  | 7 | 9         | 9  | 8  | 8  | 10 | 9       | 10 | 12 | 11 | 11 | 9        | 9  | 10 | 11 | 11 |
| 2                 | 10          | 14 | 5  | 13 | 8  | 10           | 3  | 10 | 6  | 10 | 3         | 5  | 5  | 9  | 7 | 9         | 9  | 11 | 7  | 9  | 8       | 8  | 13 | 11 | 10 | 7        | 8  | 10 | 10 | 9  |
| 3                 | 9           | 13 | 1  | 11 | 6  | 8            | 9  | 9  | 6  | 9  | 5         | 3  | 5  | 9  | 6 | 9         | 8  | 11 | 7  | 10 | 7       | 7  | 11 | 11 | 9  | 3        | 7  | 10 | 9  | 6  |
| 4                 | 5           | 11 | 0  | 7  | 3  | 8            | 9  | 8  | 3  | 8  | 7         | 3  | 4  | 8  | 8 | 9         | 5  | 11 | 9  | 8  | 7       | 6  | 8  | 10 | 9  | 3        | 5  | 12 | 9  | 4  |
| 5                 | 2           | 10 | 0  | 4  | 2  | 6            | 10 | 6  | 1  | 6  | 9         | 3  | 6  | 8  | 8 | 10        | 3  | 13 | 7  | 8  | 8       | 5  | 5  | 9  | 7  | 2        | 4  | 10 | 6  | 4  |
| 6                 | 0           | 7  | 0  | 3  | 0  | 6            | 10 | 4  | 0  | 5  | 8         | 1  | 6  | 6  | 7 | 9         | 3  | 13 | 7  | 9  | 8       | 4  | 3  | 8  | 7  | 3        | 1  | 9  | 6  | 4  |
| 7                 | 0           | 2  | 0  | 0  | 0  | 3            | 10 | 1  | 5  | 1  | 7         | 1  | 8  | 5  | 6 | 7         | 2  | 13 | 6  | 8  | 8       | 4  | 2  | 6  | 6  | 3        | 0  | 6  | 7  | 4  |
| 8                 | 0           | 0  | 9  | 0  | 6  | 2            | 8  | 3  | 6  | 0  | 5         | 3  | 9  | 9  | 6 | 6         | 4  | 13 | 6  | 8  | 7       | 6  | 2  | 5  | 6  | 2        | 2  | 4  | 4  | 4  |
| 9                 | 0           | 0  | 10 | 0  | 0  | 2            | 8  | 4  | 7  | 5  | 3         | 5  | 9  | 8  | 4 | 2         | 3  | 13 | 7  | 8  | 8       | 6  | 0  | 2  | 4  | 6        | 3  | 0  | 2  | 8  |
| 10                | 9           | 0  | 7  | 7  | 3  | 2            | 7  | 4  | 9  | 4  | 1         | 5  | 9  | 8  | 2 | 2         | 6  | 13 | 6  | 10 | 6       | 10 | 6  | 1  | 1  | 6        | 7  | 0  | 0  | 10 |
| 11                | 8           | 0  | 6  | 7  | 4  | 3            | 5  | 6  | 11 | 3  | 2         | 5  | 9  | 7  | 2 | 2         | 8  | 13 | 8  | 8  | 4       | 11 | 8  | 5  | 7  | 4        | 8  | 0  | 5  | 6  |
| 12                | 7           | 7  | 6  | 6  | 5  | 2            | 1  | 7  | 11 | 2  | 2         | 7  | 9  | 9  | 3 | 1         | 9  | 12 | 7  | 8  | 2       | 10 | 8  | 6  | 5  | 4        | 11 | 0  | 3  | 5  |
| 13                | 3           | 12 | 4  | 7  | 4  | 4            | 0  | 9  | 9  | 6  | 3         | 5  | 8  | 6  | 5 | 4         | 9  | 12 | 9  | 8  | 0       | 10 | 8  | 7  | 3  | 4        | 12 | 8  | 2  | 4  |
| 14                | 1           | 11 | 2  | 4  | 4  | 5            | 3  | 9  | 9  | 4  | 5         | 3  | 7  | 3  | 7 | 6         | 5  | 11 | 11 | 8  | 2       | 6  | 8  | 8  | 2  | 7        | 12 | 8  | 3  | 3  |
| 15                | 0           | 11 | 9  | 4  | 9  | 3            | 2  | 10 | 8  | 1  | 7         | 1  | 8  | 2  | 8 | 9         | 6  | 9  | 10 | 9  | 3       | 10 | 8  | 9  | 4  | 6        | 11 | 12 | 3  | 4  |
| 16                | 0           | 5  | 8  | 4  | 8  | 1            | 3  | 9  | 9  | 2  | 9         | 2  | 8  | 2  | 9 | 11        | 4  | 9  | 11 | 6  | 4       | 5  | 6  | 9  | 5  | 8        | 10 | 12 | 4  | 3  |
| 17                | 4           | 2  | 8  | 6  | 7  | 2            | 5  | 8  | 7  | 5  | 9         | 5  | 7  | 2  | 8 | 10        | 2  | 9  | 10 | 6  | 8       | 4  | 7  | 10 | 5  | 10       | 9  | 10 | 1  | 9  |
| 18                | 5           | 0  | 8  | 7  | 8  | 3            | 9  | 8  | 6  | 6  | 9         | 4  | 8  | 1  | 5 | 9         | 2  | 9  | 12 | 5  | 11      | 4  | 7  | 7  | 7  | 10       | 9  | 9  | 2  | 9  |
| 19                | 5           | 0  | 9  | 7  | 8  | 3            | 7  | 10 | 4  | 5  | 9         | 5  | 7  | 5  | 4 | 8         | 1  | 9  | 11 | 4  | 12      | 3  | 7  | 8  | 8  | 11       | 9  | 9  | 5  | 10 |
| 20                | 3           | 0  | 9  | 10 | 8  | 4            | 6  | 9  | 4  | 6  | 9         | 7  | 8  | 8  | 2 | 7         | 5  | 9  | 11 | 5  | 11      | 10 | 7  | 6  | 8  | 11       | 6  | 10 | 7  | 10 |
| 21                | 2           | 0  | 8  | 9  | 7  | 7            | 6  | 8  | 3  | 4  | 7         | 9  | 8  | 10 | 2 | 5         | 5  | 8  | 11 | 3  | 11      | 8  | 9  | 8  | 8  | 11       | 5  | 8  | 8  | 8  |
| 22                | 1           | 9  | 9  | 8  | 9  | 9            | 6  | 9  | 3  | 4  | 7         | 8  | 9  | 9  | 2 | 5         | 6  | 7  | 11 | 6  | 11      | 9  | 10 | 8  | 8  | 11       | 5  | 8  | 7  | 9  |
| 23                | 1           | 12 | 10 | 7  | 9  | 7            | 7  | 10 | 5  | 3  | 6         | 5  | 10 | 9  | 4 | 4         | 8  | 7  | 10 | 8  | 10      | 7  | 9  | 8  | 9  | 11       | 10 | 7  | 9  | 8  |
| 24                | 2           | 13 | 8  | 8  | 9  | 7            | 7  | 9  | 5  | 2  | 8         | 5  | 7  | 10 | 6 | 7         | 8  | 5  | 8  | 9  | 10      | 5  | 8  | 10 | 8  | 8        | 9  | 5  | 9  | 8  |
| 25                | 4           | 13 | 8  | 9  | 8  | 7            | 9  | 8  | 7  | 3  | 7         | 7  | 7  | 8  | 8 | 8         | 9  | 4  | 8  | 10 | 8       | 5  | 9  | 9  | 7  | 7        | 9  | 4  | 9  | 8  |
| 26                | 7           | 10 | 10 | 9  | 8  | 4            | 8  | 7  | 10 | 3  | 6         | 6  | 7  | 8  | 8 | 9         | 9  | 3  | 7  | 11 | 7       | 5  | 9  | 9  | 8  | 7        | 10 | 8  | 7  | 6  |
| 27                | 7           | 9  | 9  | 9  | 9  | 1            | 7  | 7  | 12 | 7  | 7         | 5  | 4  | 7  | 9 | 11        | 10 | 9  | 7  | 13 | 7       | 7  | 8  | 9  | 8  | 6        | 10 | 9  | 8  | 8  |
| 28                | 8           | 7  | 8  | 10 | 9  | 1            | 8  | 7  | 10 | 8  | 8         | 7  | 5  | 9  | 8 | 9         | 8  | 10 | 7  | 13 | 7       | 7  | 9  | 10 | 10 | 6        | 10 | 8  | 9  | 6  |
| 29                | 7           | 6  | 8  | 12 | 10 |              |    |    |    |    | 8         | 10 | 4  | 8  | 8 | 9         | 7  | 10 | 6  | 11 | 5       | 8  | 7  | 9  | 10 | 4        | 10 | 9  | 10 | 7  |
| 30                | 8           | 4  | 11 | 11 | 9  |              |    |    |    |    | 7         | 10 | 5  | 8  | 9 | 8         | 9  | 11 | 12 | 10 | 5       | 9  | 11 | 10 | 9  | 9        | 10 | 10 | 10 | 8  |
| 31                | 9           | 3  | 11 | 12 | 11 |              |    |    |    |    | 8         | 8  | 7  | 9  | 8 |           |    |    |    |    | 10      | 10 | 10 | 10 | 11 |          |    |    |    |    |



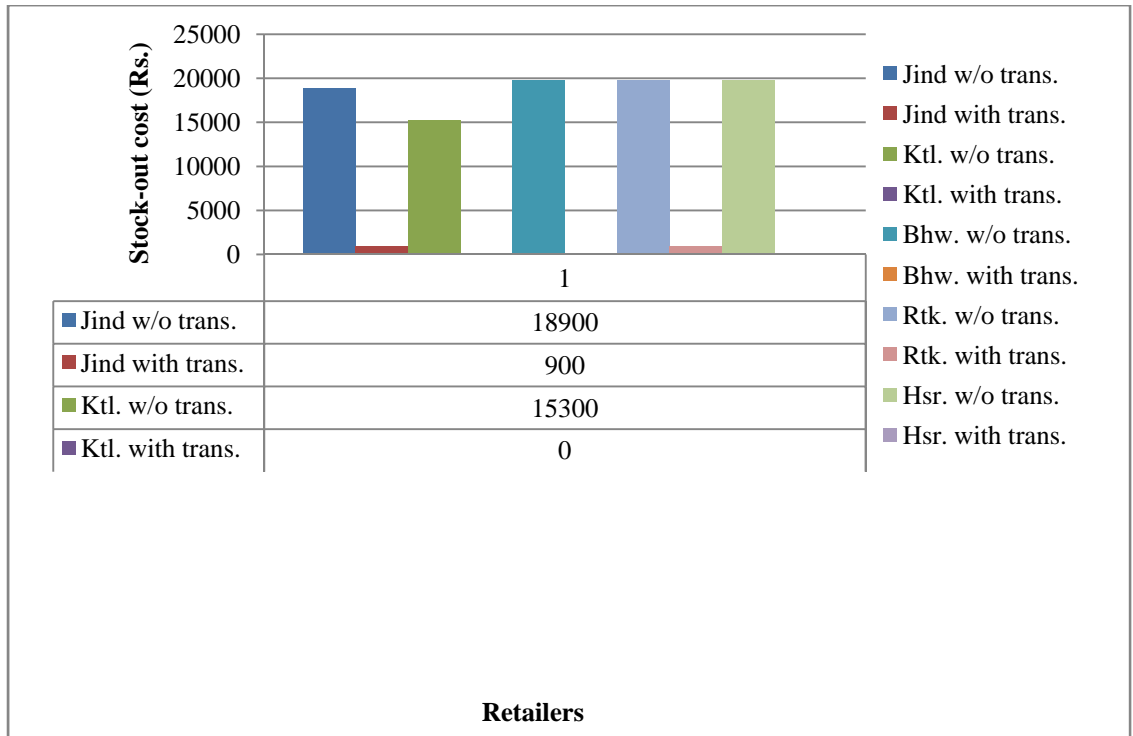
**Figure 5.2 Surplus quantities with and without transshipment (BAL).**



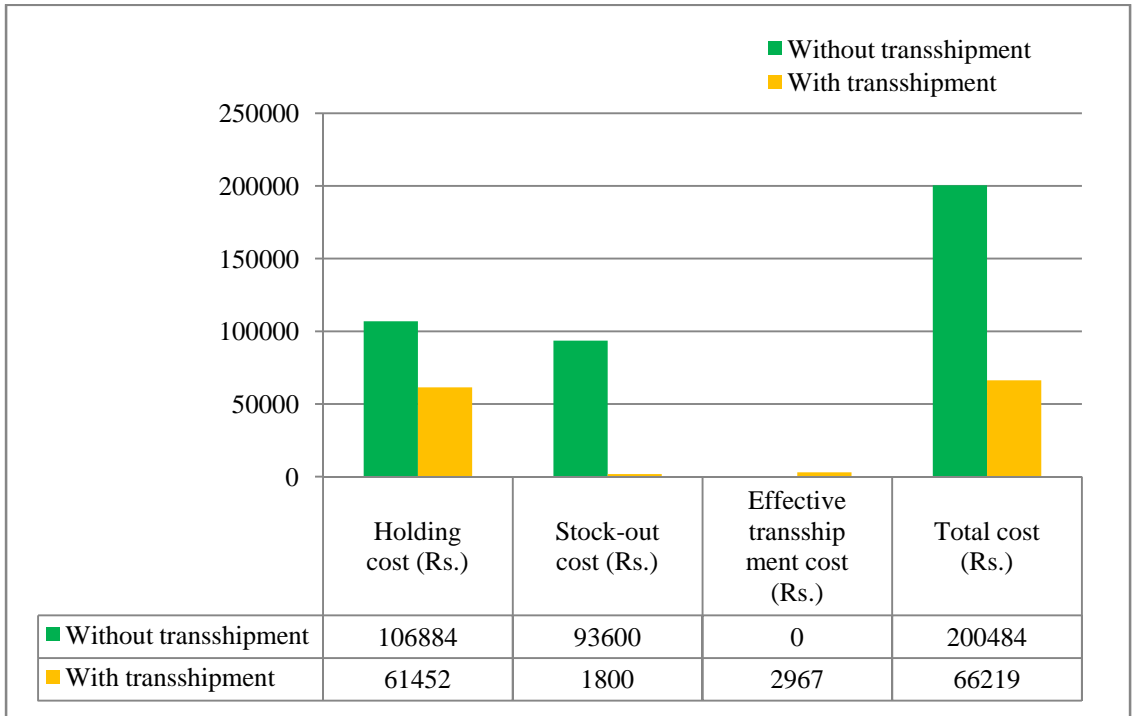
**Figure 5.3 Holding cost with and without transshipment (BAL).**



**Figure 5.4 Stock-out quantities with and without transshipment (BAL).**



**Figure 5.5 Stock-out cost with and without transshipment (BAL).**



**Figure 5.6 Comparison of holding, stock-out, effective transshipment and total cost with and without transshipment (BAL).**

**Table 5.3 Service levels with and without transshipment (BAL).**

| <b>Retailers</b> | <b>Demand service level</b>      |                               | <b>Period service level</b>      |                               |
|------------------|----------------------------------|-------------------------------|----------------------------------|-------------------------------|
|                  | <b>Without transshipment (%)</b> | <b>With transshipment (%)</b> | <b>Without transshipment (%)</b> | <b>With transshipment (%)</b> |
| Jind             | 91                               | 99                            | 92                               | 99                            |
| Kaithal          | 93                               | 100                           | 91                               | 100                           |
| Bhiwani          | 87                               | 100                           | 92                               | 100                           |
| Rohtak           | 89                               | 99                            | 92                               | 99                            |
| Hissar           | 89                               | 100                           | 91                               | 100                           |

### CASE STUDY - 3

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#### 6.1 HERO HONDA MOTORS LIMITED (HHML)

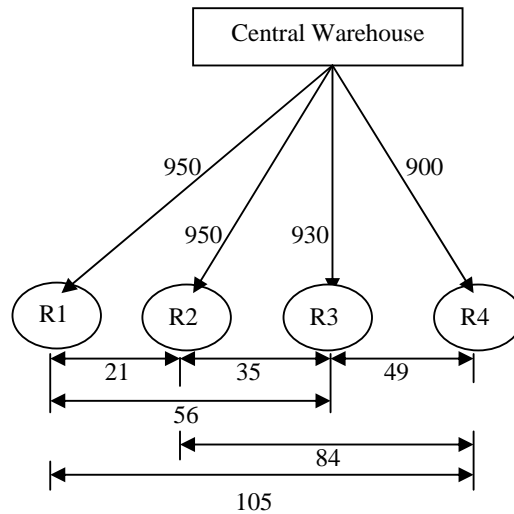
“Hero” is the brand name used by the Munjal brothers for their flagship company Hero Cycles Ltd. During the 1980s, the company introduced motorcycles that were popular in India for their fuel economy and low cost. Hero Honda Motors Limited has three manufacturing facilities based at Dharuhera and Gurgaon in Haryana and at Haridwar in Uttarakhand. These plants together are capable of churning out 3.9 million bikes per year. The Company established in 1985 a joint venture between Hero Group of India and Honda of Japan holds a 50% market share in India and has grown to become the world’s largest two-wheeler manufacturer. This company has large sales and service network with over 3000 dealership and service points across India.

Two-wheeler in India is a synonymous to the brand Hero Honda, a unit of Hero Group. Company’s existing structure of the supply chain and the proposed one, is same as taken earlier given by figure 4.1 and figure 4.2 respectively.

#### 6.2 DATA COLLECTION

Collected data for the brand (Splendor-plus) covering day wise demand and daily opening stock, is given in appendix-E for the 4 retailers [R1-Dadri (D), R2-Bhiwai (B), R3-Rohtak (R), R4-Sonepat (S)] for the months of May, 2009 to September, 2009. This practice of extending the case study is done to strengthen the quality of the text.

Holding cost/bike/day is Rs. 11.50, stock-out cost/bike is Rs. 1000/- and transportation cost from central warehouse to different retailers and emergency lateral transshipment cost amongst retailers is shown in figure 6.1.



**Figure 6.1 Transshipment cost from central warehouse and between retailers (HHML).**

### 6.3 RESULTS AND DISCUSSIONS

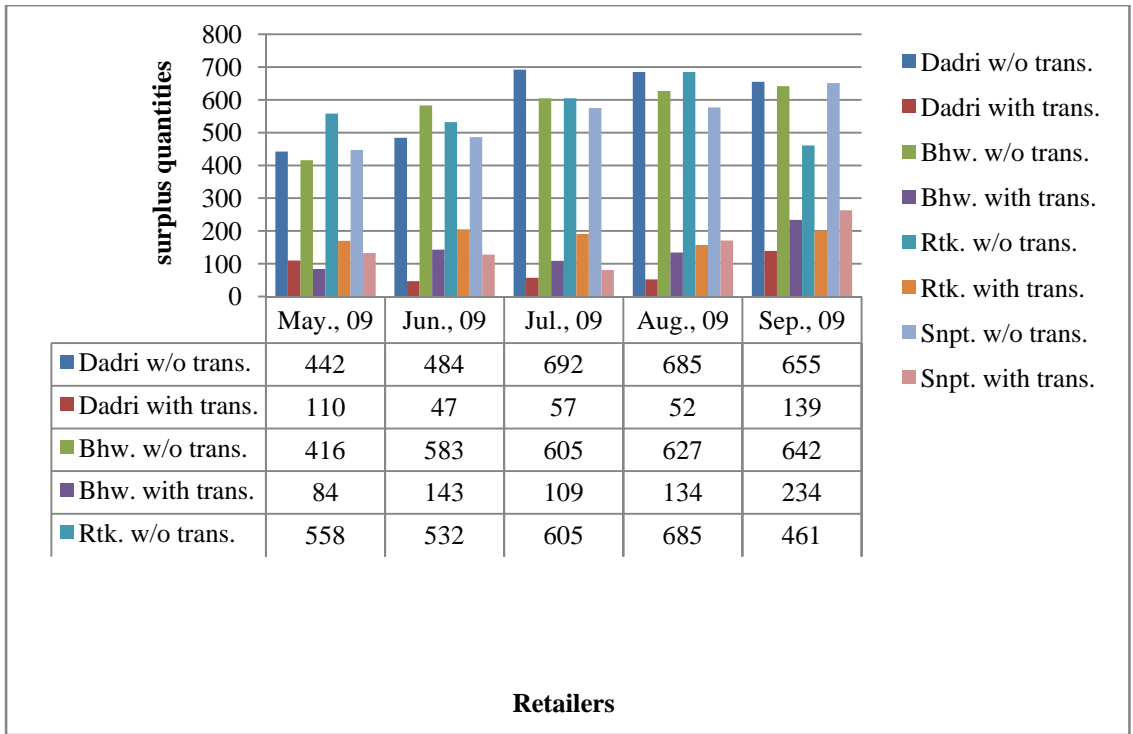
Table 6.1 gives the observations for inventory related parameters; table 6.2 and Appendix-E represent the available inventory with transshipment and without transshipment respectively. It has been analyzed that following the lateral transshipment, the level of surplus quantities, holding cost, stock-out quantities, and stock-out cost has been reduced as shown in figure 6.2 to 6.5 respectively and it has also been observed that while adopting lateral transshipment approach the total associated cost also decreases to significant amount as shown in figure 6.6. Enhancement in demand service level and period service level are given by table 6.3.

**.Table 6.1 Observations for related parameters (HHML).**

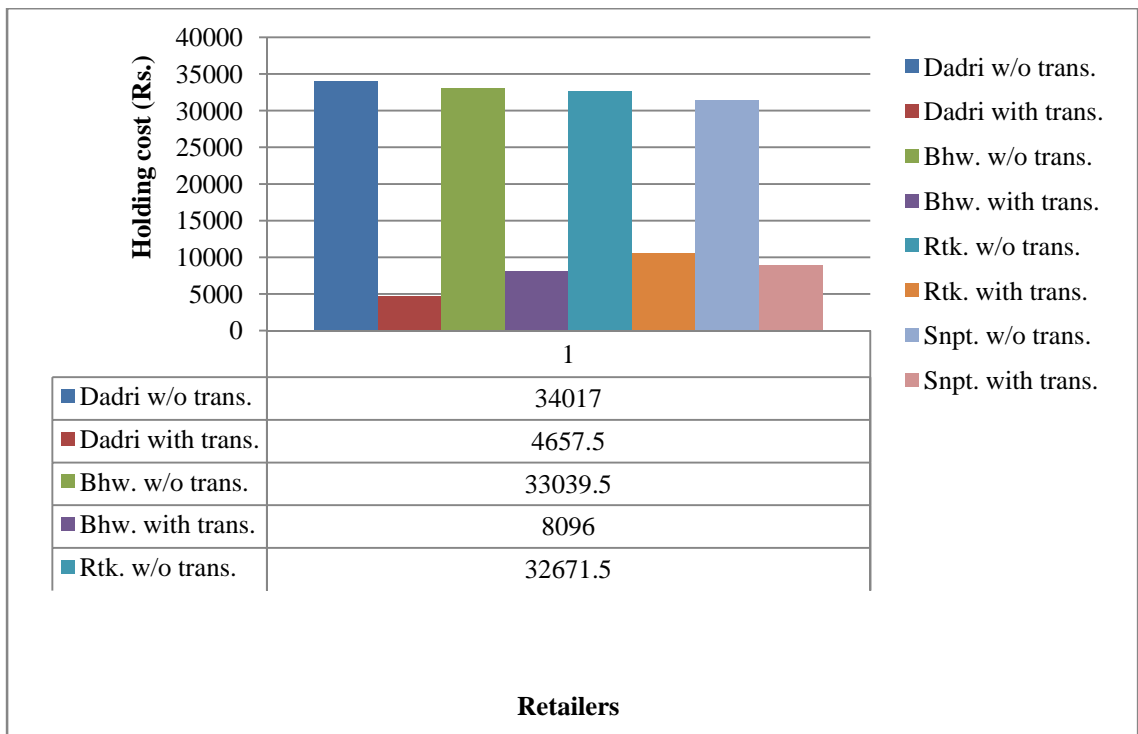
| Calculations                     | Product (Platina-125) |      |      |      |
|----------------------------------|-----------------------|------|------|------|
|                                  | D                     | B    | R    | S    |
| Mean demand                      | 1                     | 2    | 2    | 2    |
| Mean lead-time                   | 5                     | 5    | 5    | 5    |
| Standard deviation for demand    | 2                     | 2    | 2    | 2    |
| Standard deviation for lead-time | 2                     | 2    | 2    | 2    |
| Demand variation                 | 0-7                   | 0-8  | 0-8  | 0-8  |
| Lead-time variation              | 0-11                  | 0-11 | 0-11 | 0-11 |
| Max. level of inventory          | 8                     | 16   | 16   | 16   |
| Reorder level                    | 5                     | 10   | 10   | 10   |

**Table 6.2 Total inventory available with transshipment (HHML).**

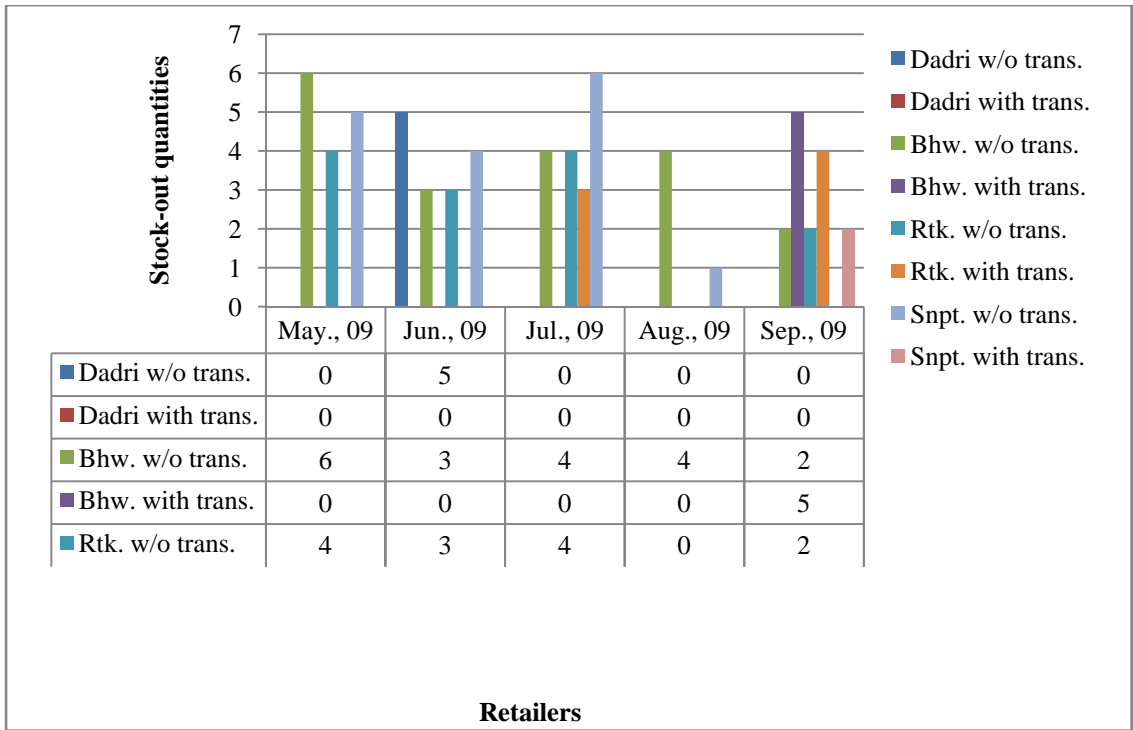
| In-hand inventory | May, 09 |    |    |    | June, 09 |    |    |    | July, 09 |    |    |    | August, 09 |    |    |    | September, 09 |    |    |    |
|-------------------|---------|----|----|----|----------|----|----|----|----------|----|----|----|------------|----|----|----|---------------|----|----|----|
|                   | D       | B  | R  | S  | D        | B  | R  | S  | D        | B  | R  | S  | D          | B  | R  | S  | D             | B  | R  | S  |
| 1                 | 13      | 5  | 17 | 3  | 4        | 5  | 9  | 13 | 3        | 8  | 4  | 0  | 0          | 0  | 10 | 10 | 6             | 8  | 11 | 11 |
| 2                 | 13      | 3  | 15 | 0  | 3        | 4  | 10 | 11 | 1        | 1  | 0  | 4  | 0          | 2  | 5  | 9  | 6             | 11 | 6  | 12 |
| 3                 | 12      | 2  | 14 | 0  | 2        | 2  | 11 | 11 | 1        | 0  | 5  | 2  | 1          | 0  | 1  | 7  | 5             | 10 | 2  | 10 |
| 4                 | 10      | 0  | 13 | 0  | 2        | 1  | 11 | 7  | 2        | 0  | 0  | 5  | 0          | 4  | 0  | 4  | 6             | 9  | 0  | 10 |
| 5                 | 9       | 0  | 10 | 0  | 1        | 1  | 12 | 2  | 0        | 4  | 1  | 2  | 0          | 5  | 0  | 1  | 6             | 9  | 0  | 10 |
| 6                 | 7       | 0  | 9  | 0  | 0        | 0  | 11 | 0  | 0        | 0  | 1  | 3  | 2          | 8  | 0  | 4  | 6             | 8  | 0  | 10 |
| 7                 | 1       | 0  | 6  | 0  | 0        | 3  | 8  | 1  | 1        | 2  | 0  | 4  | 3          | 8  | 0  | 3  | 6             | 11 | 0  | 10 |
| 8                 | 0       | 0  | 2  | 0  | 1        | 5  | 8  | 0  | 2        | 3  | 5  | 4  | 6          | 7  | 6  | 4  | 6             | 10 | 0  | 12 |
| 9                 | 0       | 13 | 0  | 16 | 1        | 9  | 8  | 3  | 2        | 11 | 8  | 3  | 6          | 7  | 7  | 5  | 6             | 7  | 8  | 13 |
| 10                | 0       | 13 | 0  | 12 | 3        | 6  | 9  | 3  | 3        | 11 | 8  | 6  | 5          | 9  | 11 | 7  | 7             | 8  | 13 | 14 |
| 11                | 0       | 12 | 0  | 9  | 0        | 7  | 3  | 7  | 4        | 10 | 13 | 7  | 2          | 8  | 12 | 4  | 7             | 10 | 15 | 14 |
| 12                | 0       | 12 | 6  | 7  | 2        | 2  | 0  | 12 | 6        | 7  | 13 | 10 | 2          | 7  | 8  | 3  | 7             | 10 | 15 | 14 |
| 13                | 0       | 10 | 6  | 4  | 1        | 1  | 0  | 9  | 6        | 11 | 12 | 8  | 1          | 9  | 6  | 0  | 6             | 11 | 15 | 14 |
| 14                | 7       | 9  | 9  | 1  | 0        | 0  | 4  | 4  | 5        | 9  | 13 | 3  | 0          | 10 | 3  | 1  | 6             | 10 | 15 | 14 |
| 15                | 8       | 9  | 11 | 0  | 0        | 3  | 1  | 3  | 3        | 9  | 12 | 0  | 1          | 9  | 0  | 2  | 7             | 12 | 15 | 14 |
| 16                | 7       | 5  | 13 | 0  | 1        | 2  | 2  | 2  | 5        | 9  | 4  | 1  | 1          | 8  | 4  | 2  | 7             | 15 | 15 | 14 |
| 17                | 7       | 0  | 11 | 0  | 2        | 6  | 1  | 3  | 4        | 10 | 2  | 0  | 1          | 6  | 4  | 1  | 7             | 15 | 16 | 14 |
| 18                | 3       | 4  | 10 | 7  | 4        | 7  | 7  | 3  | 4        | 8  | 0  | 1  | 5          | 6  | 4  | 7  | 7             | 15 | 15 | 14 |
| 19                | 3       | 0  | 8  | 6  | 2        | 9  | 10 | 1  | 3        | 7  | 0  | 3  | 3          | 2  | 4  | 10 | 7             | 15 | 15 | 14 |
| 20                | 0       | 2  | 7  | 9  | 4        | 11 | 9  | 6  | 3        | 2  | 0  | 5  | 4          | 1  | 6  | 13 | 5             | 13 | 10 | 8  |
| 21                | 0       | 1  | 7  | 11 | 4        | 12 | 9  | 11 | 2        | 2  | 0  | 5  | 2          | 2  | 9  | 13 | 3             | 10 | 6  | 5  |
| 22                | 0       | 1  | 6  | 12 | 4        | 11 | 13 | 12 | 2        | 0  | 0  | 3  | 1          | 3  | 10 | 13 | 1             | 8  | 3  | 4  |
| 23                | 0       | 4  | 1  | 9  | 3        | 12 | 14 | 13 | 2        | 0  | 12 | 1  | 0          | 2  | 8  | 11 | 0             | 2  | 0  | 0  |
| 24                | 0       | 5  | 0  | 7  | 3        | 10 | 12 | 12 | 1        | 0  | 14 | 1  | 1          | 2  | 7  | 11 | 0             | 0  | 0  | 0  |
| 25                | 5       | 0  | 3  | 5  | 3        | 9  | 12 | 9  | 1        | 3  | 16 | 1  | 0          | 3  | 7  | 10 | 0             | 0  | 0  | 0  |
| 26                | 3       | 4  | 2  | 7  | 4        | 12 | 10 | 10 | 2        | 5  | 15 | 1  | 2          | 6  | 11 | 9  | 0             | 0  | 0  | 0  |
| 27                | 6       | 2  | 2  | 6  | 3        | 11 | 11 | 5  | 1        | 10 | 15 | 3  | 2          | 7  | 9  | 9  | 3             | 0  | 6  | 8  |
| 28                | 6       | 3  | 2  | 7  | 4        | 8  | 10 | 3  | 3        | 8  | 14 | 8  | 4          | 7  | 9  | 8  | 5             | 6  | 8  | 8  |
| 29                | 5       | 3  | 4  | 7  | 4        | 9  | 9  | 1  | 5        | 8  | 14 | 13 | 5          | 8  | 11 | 8  | 6             | 7  | 11 | 8  |
| 30                | 5       | 4  | 9  | 10 | 4        | 7  | 9  | 0  | 3        | 3  | 13 | 12 | 6          | 10 | 13 | 8  | 7             | 13 | 14 | 12 |
| 31                | 5       | 5  | 10 | 11 |          |    |    |    | 4        | 0  | 11 | 12 | 6          | 9  | 12 | 12 |               |    |    |    |



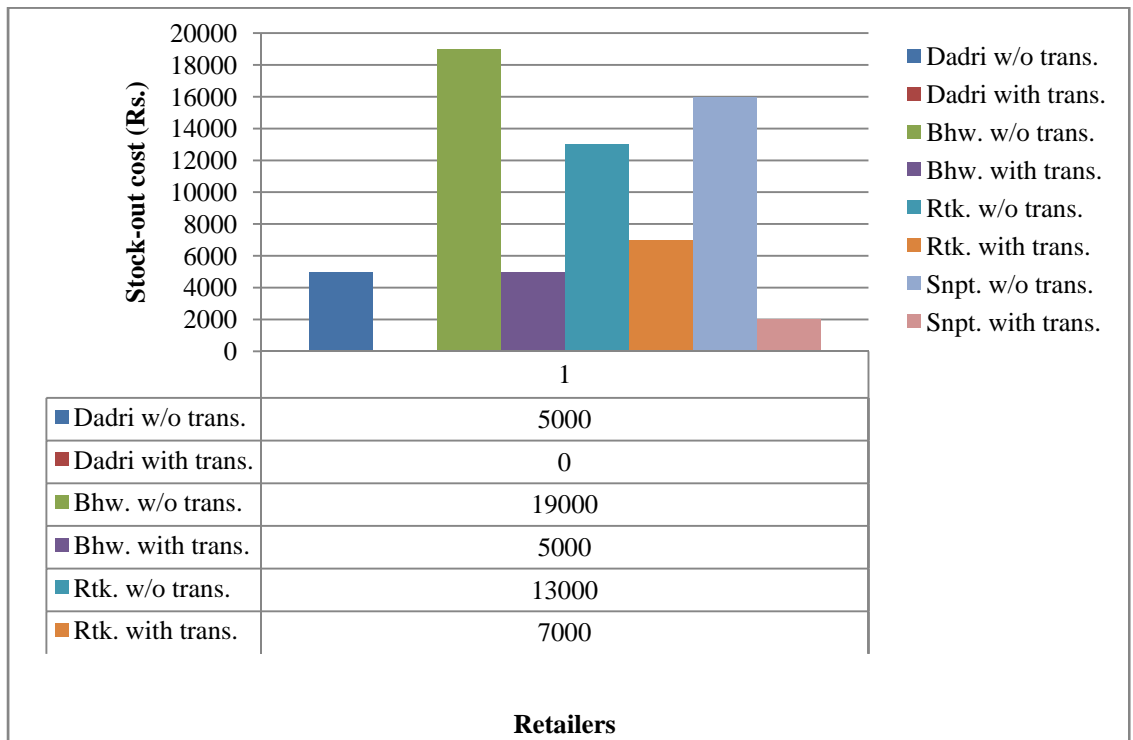
**Figure 6.2 Surplus quantities with and without transshipment (HHML).**



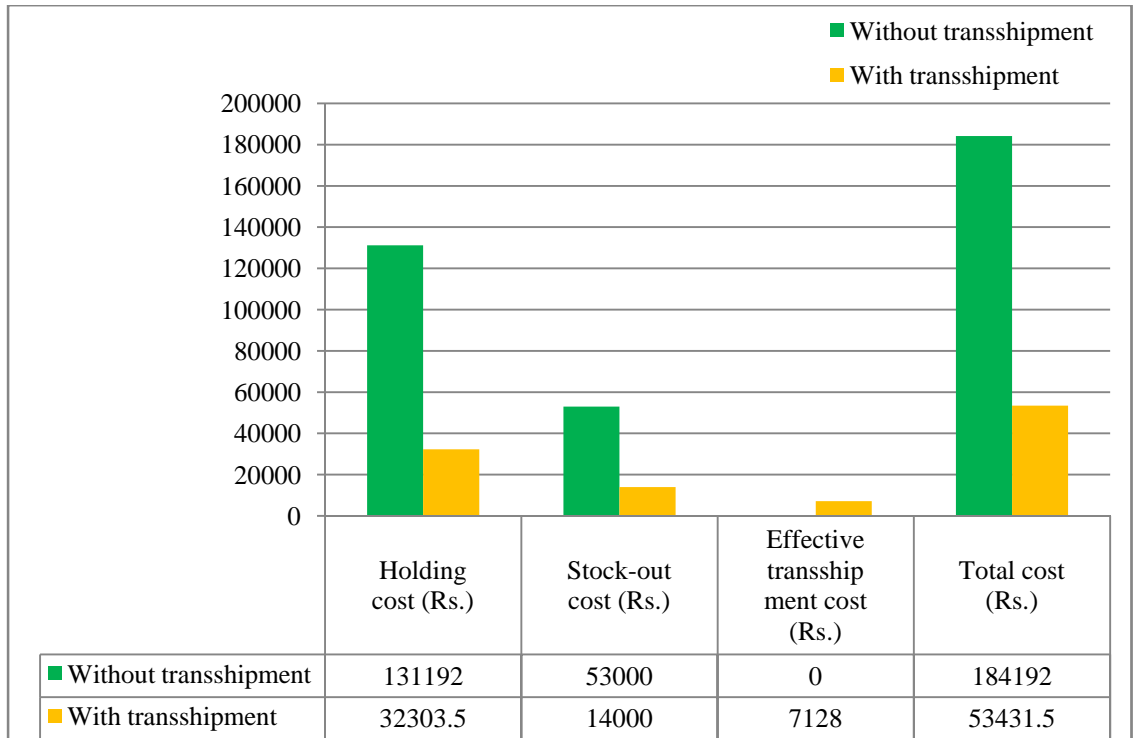
**Figure 6.3 Holding cost with and without transshipment (HHML).**



**Figure 6.4 Stock-out quantities with and without transshipment (HHML).**



**Figure 6.5 Stock-out cost with and without transshipment (HHML).**



**Figure 6.6 Comparison of holding, stock-out, effective transshipment and total cost with and without transshipment (HHML).**

**Table 6.3 Service levels with and without transshipment (HHML).**

| Retailers | Demand service level      |                        | Period service level      |                        |
|-----------|---------------------------|------------------------|---------------------------|------------------------|
|           | Without transshipment (%) | With transshipment (%) | Without transshipment (%) | With transshipment (%) |
| Dadri     | 95                        | 100                    | 98                        | 100                    |
| Bhiwani   | 91                        | 98                     | 92                        | 99                     |
| Rohtak    | 94                        | 97                     | 95                        | 99                     |
| Sonepat   | 92                        | 99                     | 93                        | 100                    |

### CONCLUSIONS AND FURTHER SCOPE OF THE WORK

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#### 7.1 CONCLUSIONS

In a supply chain, the inventory control problems have become more complex and demanding because the managers need to assess several interacting and interconnecting factors. Among them demand and lead-time uncertainties contribute to immense inventory investments in the supply chain systems. A commonly used strategy to introduce elasticity and overcome uncertainties is to establish transshipment links between locations at the same echelon. By implementing the supply chain management optimization, the auto manufacturers in India may enormously augment their intact supply chain process and, it has been found that uncertainties like demand and lead-time have undying impact on managing inventories. Retailers in the supply chain face immense difficulties while controlling the same. Achieving better customer satisfaction and cost reduction are further key issues to be handled effectively in the present competitive environment.

In this work, a multi-location inventory system has been considered where effective lateral transshipments are allowed as recourse actions in order to reduce the inventory cost after the demands having been realized. A simple and intuitive model has been formulated that enables to characterize optimum inventory and transshipment policy for  $n$  number of locations with  $\lambda$  products, outfit by a single warehouse where stock is held to meet customers' demands. Model is based on variable holding, stock-out and effective transshipment costs between retailers because in real practice retailers are not equally apart. Using this model an in-house program has been formulated in C++ which is executed on the data collected from the three Indian based automobile manufacturing companies and the outcomes (with transshipment) have been compared with the existing results of the companies (without transshipment) and it has been found that in the case of Maruti Udyog Ltd. the holding cost has been reduced by 43.4%, stock-out cost by 95.45% and total cost by 66.82%. Service levels have been improved from 6-10% approximately. When the

same strategy was adopted for Bajaj Auto Ltd. all the above mentioned costs like holding, stock-out, total cost was reduced by 42.5%, 98.07% and 66.97% respectively and the service levels were also improved 7-13% approximately. Same improvements in the costs and service levels have also been observed in the third case study i.e. Hero Honda Motors Ltd. which can be analyzed from its graphical results given in figures 6.3, 6.5 and 6.6 and table 6.2 respectively. Based on the results of the above discussed three case studies, this work has been examined from a cost-parametric perspective, the relative effectiveness of a transshipment approach in supply chain network characterized by a single supply source at the higher echelon and multiple retail locations at the lower echelon.

Adopted emergency lateral transportation approach has enabled to gain analytical insight into problems of higher dimensions (covering more number of retailers with numerous products) than achieved earlier. This heterogeneous approach is used for controlling inventories and associated costs (holding, stock-out, effective transshipment and total cost) at retailers end. It is applicable for individual retailer, as well as group of retailers, participating in sharing of inventory during emergency. Service levels have also been enhanced with the implementation of emergency lateral transshipment approach. Our results indicate that, from a managerial standpoint, the notion of lateral transshipments appears to have substantial appeal. If the benefits of avoiding retail level shortages outweigh the additional delivery costs resulting from transshipments, customer service may be enhanced significantly, without the burden of additional safety stocks.

It is pertinent to mention that the emergency lateral transshipment approach is ineffective, when all retailers, in every period, showing same pattern of surplus and stock-out. To make risk-pooling (lateral transshipment) strategy more effective, there should be close, healthy and transparent relations amongst retailers. It is win-win situation to all the retailers and an efficient tool to strengthen the whole supply chain.

Finally it may be concluded that by using lateral transshipment transportation cost is increased, yet it is a superior approach than a policy of no transshipments because total cost associated is less and better customer satisfaction may be achieved with accessible inventory by overcoming the uncertainties of demand and lead-time.

## **7.2 FURTHER SCOPE OF THE WORK**

Managing crosswise all nodes of the supply chain from the supplier's supplier to customer's customer is of paramount importance in the current scenario. A clear understanding of the supply chain concepts and to share information explicitly between supply chain partners have become imperative. Two or more than two sources with limited capacity may be considered as reservoirs as a single warehouse with unlimited capacity has been considered in this work. Variability in lateral transshipment delivery time may also be introduced as the above work allows emergency lateral transshipment to take place on the same day amongst the retailers. Different uncertainties like manufacturing lead-time, suppliers' problems, market trends, product life cycle and information flow system may be explored further for controlling inventories in the supply chain. These will be interesting issues for future research.

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## APPENDIX- A

### Program Formulation for 'n' Retailers (Without Transshipment)

```
#include<iostream.h>
#include<stdlib.h>
#include<conio.h>
#include<dos.h>
#include<string.h>
#define SIZE 50
int i,k,s,j, $\lambda$ ,min,loc,maxinventory,noper,nodays,meandem,meanldtm,revtm,
reorderlvl,bkrcost[20],surpcost[20],demvar1,timvar1,demvar2,timvar2,di[5][5];
int temp,distcharge;
void thanku();
void sort(int x[],int n)
{
    int i,j, temp;
    for(i=0;i<n-1;i++)
        for(j=i+1;j<n;j++)
            {
                if(x[i]> x[j])
                {
                    temp=x[i];
                    x[i]=x[j];
                    x[j]=temp;
                }
            }
    return;
}
}
class inventory
{
    int sno;
    int demand;
    int inhaninventory_start ;
    int inventoryreached_day;
    int totalinventory_start;
    int surplusquantity;
    int stockoutquantity;
    int orderedquantity;
    int leadtime;
    int recievingday_inventory;
    int demandsatisfied;
    int totaldemand;
    int noofperioddelivered;
    int totalperiod;

public:
```

```

inventory()
{
    sno=0;
    demand=0;
    inhaninventory_start =0;
    inventoryreached_day=0;
    totalinventory_start=0;
    surplusquantity=0;
    stockoutquantity=0;
    orderedquantity=0;
    leadtime=0;
    recievingday_inventory=0;
    intransitinventory=0;
    demandsatisfied=0;
    totaldemand=0;
    noofperioddelivered=0;
    totalperiod=0;
//      transcost=0;
}
void input();
void adjust();
void display()
{
    cout<<"Day no: "<<sno<<endl;
    cout<<"Demand: "<<demand<<endl;
    cout<<"Inhand inventory at start: "<<inhaninventory_start<<endl;
    cout<<"Inventory reached at theday: "<<inventoryreached_day<<endl;
    cout<<"Total inventory at start: "<<totalinventory_start<<endl;
    cout<<"Surplus: "<<surplusquantity<<endl;
    cout<<"Stockout: "<<stockoutquantity<<endl;
    cout<<"Ordered quantity: "<<orderedquantity<<endl;
    cout<<"Lead-time: "<<leadtime<<endl;
    cout<<"Inventory recieving Day: "<<recievingday_inventory<<endl;
    cout<<"Intransitinventory: "<<intransitinventory<<endl;
    cout<<"Holding cost : Rs."<<surplusquantity*surpcost[k]<<endl;
    cout<<"Backorder cost : Rs."<<stockoutquantity*bkorcost[k]<<endl;
    cout<<"Transshipment Cost : Rs."<<transcost*distcharge<<endl;
    cout<<"Demand Satisfaction
Level"<<demandsatisfied/totaldemand<<endl;
    cout<<"Period Satisfaction
Level"<<noofperioddelivered/totalperiod<<endl;
    cout<<"Transshipment Cost : Rs."<<transcost*distcharge<<endl;
    cout<<"Transshipment Cost : Rs."<<transcost*distcharge<<endl;
    cout<<"Transshipment Cost : Rs."<<transcost*distcharge<<endl;
}

```

```

        cout<<“\n-----”
--”;
    }
    void final();
    void testy();

}inventory_arr[SIZE][SIZE];

void inventory :: input()
{
    if(i==0)
    {
        cout<<“ENTER STARTING INVENTORY    :”;
        cin>>inhaninventory_start;
        cin>> λ;

    }

    cout<<“\nEnter the Demand (b/w “<<demvar1<<“ and
“<<demvar2<<“): “;
    do
    {
        cin>>demand;
        if((demand<demvar1) || (demand>demvar2))
            cout<<“\nInvalid value, please re-enter the demand
(b/w “<<demvar1<<“ and “<<demvar2<<“): “;
        }while((demand<demvar1) || (demand>demvar2));
    cout<<“\nEnter the Demand Satisfied”;
    cin>>demandsatisfied;
    cout<<“\nEnter the Total Demand”;
    cin>>totaldemand;
    cout<<“\nEnter the No Of Period Delivered”;
    cin>>noofperioddelivered;
    cout<<“\nEnter the Total Period”;
    cin>>totalperiod;

    cout<<“\nEnter the Lead-time (b/w “<<timvar1<<“ and
“<<timvar2<<“): “;
    do
    {
        cin>>leadtime ;
        if((leadtime<timvar1) || (leadtime>timvar2))
            cout<<“\nInvalid value, please re-enter the Lead-time
(b/w “<<timvar1<<“ and “<<timvar2<<“): “;
        }while((leadtime<timvar1) || (leadtime>timvar2));
    totalinventory_start=inhaninventory_start+inventoryreached_day;

```

```

surplusquantity=totalinventory_start-demand;
if(surplusquantity >= 0)
    stockoutquantity=0;
else
{
    stockoutquantity= -(surplusquantity);
    surplusquantity=0;
}
}
void inventory :: adjust()
{
for(int y=0;y<3;y++)
    for(int z=0;z<nodays;z++)
    {
        int s1=inventory_arr[0][z].surplusquantity;
        int s2=inventory_arr[1][z].surplusquantity;
        int s3=inventory_arr[2][z].surplusquantity;
        int arr[]={s1,s2,s3};
        sort(arr,3);
        if(arr[0]<0 || arr[1]<0 || arr[2]<0)
        {
            if(arr[0]<0)
            {
                int temp=-arr[0];
                if(arr[2]>temp)
                {
                    arr[2]-=temp;
                    arr[0]=0;
                }
                else
                {
                    int temp2=temp-arr[2];
                    arr[2]=0;
                    arr[1]-=temp2;
                    arr[0]=0;
                }
            }
            if (arr[0] <0)
            arr[0]=0;
            if (arr[1] <0)
            arr[1]=0;
            if (arr[2] <0)
            arr[0]=0;
            inventory_arr[0][z].surplusquantity=arr[0];
            inventory_arr[1][z].surplusquantity=arr[1];
            inventory_arr[2][z].surplusquantity=arr[2];
        }
    }
}
}

```

```

        if(surplusquantity>=reorderlvl)
            orderedquantity=0;
        else
            orderedquantity=maxinventory-
(surplusquantity+intransitinventory);
        for(int j=1;j<=leadtime;j++)
            inventory_arr[k][i+j].intransitinventory+=orderedquantity;
        sno=i+1;
        recievingday_inventory=sno+1+leadtime ;
        inventory_arr[k][i+1].inhaninventory_start=surplusquantity;
        int x=sno+1+leadtime;
        if(inventory_arr[k][x-1].inventoryreached_day==0)
            inventory_arr[k][x-1].inventoryreached_day=orderedquantity;
        else
            inventory_arr[k][x-1].inventoryreached_day+=orderedquantity;
        if(surplusquantity<0)
            surplusquantity=0;
        if(orderedquantity<0)
            orderedquantity=0;
    }
    /*void inventory :: testy()
    {
    int x,y,di_testy[5][5];
    s=k;
    for(x=0;x<5;x++)
    {
        for(y=0;y<5;y++)
        {
            di_testy[x][y]=0;
        }
    }
    for(x=0;x<noper;x++)
    {
        for(y=x+1;y<noper;y++)
        {
            di_testy[x][y]=di[x][y];
        }
        cout<<endl;
    }
    while(stockoutquantity>0)
    {
    min=di_testy[k][0];
    if(min==0)
    {
    min=di_testy[k][1];
    loc=1;
    }
    for(j=0;j<noper;j++)

```



```

        s=s-1;
    }
    else
    {
        stockoutquantity=0;
        inventory_arr[s-1][i+1].inhaninventory_start=inventory_arr[s-
1][i].surplusquantity;
    }
}while(s>=0 && stockoutquantity!=0) ;

    }
    else
    {

    }
}
di_testy[k][loc]=0;
}
}*/
void inventory :: final()
{
    cout<<“\n\t\t\t\tOVERVIEW”<<endl;
    int a,b,c,d,e,f,g;
    for(i=0;i<noper;i++)
    {
        a=0;
        b=0;
        c=0;
        d=0;
        e=0;
        f=0;
        g=0;
        for(int j=0;j<nodays;j++)
        {
            c+=(inventory_arr[i][j].surplusquantity);
            d+=(inventory_arr[i][j].stockoutquantity);
            e+=(inventory_arr[i][j].totalinventory_start);
            f+=(inventory_arr[i][j].orderedquantity);
            a+=(inventory_arr[i][j].surplusquantity*surpcost[i]);
            b+=(inventory_arr[i][j].stockoutquantity*bkorcost[i]);
            g+=(inventory_arr[i][j].transcost);
        }
        cout<<“\n\nRetailer “<<i+1<<endl;
        cout<<“\n\tTotal Surplus quantity : “<<c;
        cout<<“\n\tTotal StockOut quantity : “<<d;
        cout<<“\n\tTotal inventory at start : “<<e;
        cout<<“\n\tTotal ordered quantity : “<<f;
        cout<<“\n\tTotal holding cost : Rs.”<<a;
    }
}

```

```

        cout<<“\n\tTotal backorder cost : Rs.”<<b;
        cout<<“\n\tTotal cost : Rs.”<<a+b;
        cout<<“\n\tTotal Transshipment Cost : Rs.”<<g*distcharge;
    }
}

int main()
{
    int j,sdmd,sdlt,y;
//    clrscr();
    cout<<“-----INVENTORY SIMULATION MODEL-----
\n”<<endl;
    cout<<“Of how many days you want to keep the record: “;
    cin>>nodays;
    cout<<“\nWhat is the mean Demand: “;
    cin>>meandem;
    cout<<“\nWhat is the standard deviation from mean Demand: “;
    cin>>sdmd;
    cout<<“\nWhat is the mean Lead-time: “;
    cin>>meanldtm;
    cout<<“\nWhat is the standard deviation from mean Lead-time: “;
    cin>>sdlt;
    cout<<“\nWhat is the per Kilometer Transshipment Cost: “;
    cin>>distcharge;
    demvar1=meandem-3*sdmd;
    timvar1=meanldtm-3*sdlt;
    demvar2=meandem+3*sdmd;
    timvar2=meanldtm+3*sdlt;

    if(demvar1<0)
        demvar1=0;
    if(demvar2<0)
        demvar2=0;
    if(timvar1<0)
        timvar1=0;
    if(timvar2<0)
        timvar2=0;
    cout<<“\nWhat is the Review Time: “;
    cin>>revtm;
    cout<<“\nEnter the number of retailers: “;
    cin>>noper;

    for(i=0;i<noper;i++)
    {
        for(k=i+1;k<noper;k++)
        {
            cout<<“ENTER THE DISTANCE bw RETAILER “<<i+1<<“
AND “<<k+1<<“ .”;
```

```

        cin>>di[i][k];
        di[k][i]=di[i][k];
    }    cout<<endl;
}

for(k=0;k<noper;k++)
{
    cout<<"\nEnter the per unit backorder cost for retailer "<<k+1<<" : ";
    cin>>bkorcost[k];
    cout<<"\nEnter the per unit surplus cost for retailer "<<k+1<<" : ";
    cin>>surpcost[k];
}
maxinventory=(meanldtm+revtm)*meandem;
reorderlvl=meanldtm*meandem;

for(i=0;i<nodays;i++)
{
    for(k=0;k<noper;k++)
    {
        cout<<"\n\nPlease enter the values for retailer "<<k+1<<" for
day "<<i+1<<endl;
        inventory_arr[k][i].input();
        inventory_arr[k][i].adjust();
    }
    /*
    for(k=0;k<noper;k++)
    {
        inventory_arr[k][i].testy();
    }*/
    cout<<endl;
}
int r,x;
cout<<"\nDo you want to see the result(y/n): ";
char choice;
cin>>choice;
if((choice=='n')||(choice=='N'))
    exit(0);
do
{
    cout<<"How u want to see the result \n1. Between two days \n2.
Specific day";
    int selection;
    cin>>selection;
    if(selection==2)
    {
        cout<<"\nFor which day u want to see the result: ";
        cin>>x;
        r=x-1;
//        clrscr();

```

```

        for(k=0;k<noper;k++)
        {
            j=k+1;
            if(j%3==0)
            {
                getch();
                clrscr();
            }
            cout<<"\n\nThe values for retailer "<<k+1<<" are as follows:
\n";

            cout<<endl;
            inventory_arr[k][r].display();
        }
    }
else
{

        cout<<"\n\nFrom which day to which day u want to see the result: ";
        cin>>x;
        r=x-1;
        cin>>y;
        y=y-1;
        //
        clrscr();

        for(;r<=y;r++)
        {
            for(k=0;k<noper;k++)
            {
                j=k+1;
                if(j%3==0)
                {
                    getch();
                    clrscr();
                }
                cout<<"\n\nThe values for retailer "<<k+1<<" are as follows:
\n";

                cout<<endl;
                inventory_arr[k][r].display();
            }
        }

        cout<<"\n\nDo you want to see the result again(y/n): ";
        cin>>choice;
    } while(choice=='y' || choice=='Y');
    inventory_arr[0][0].final();
    getch();
    thanku();

```

```
}  
  
void thanku()  
{  
// clrscr();  
char t[]="!!!!!!!!THANK YOU!!!!!!!!";  
// gotoxy(25,15);  
for(int i=0;i<strlen(t);i++)  
{  
// delay(50);  
cout<<t[i];  
}  
getch();  
}
```

## APPENDIX – B

### Program Formulation for ‘n’ Retailers (With Transshipment)

```
#include<iostream.h>
#include<stdlib.h>
#include<conio.h>
#include<dos.h>
#include<string.h>
#define SIZE 180
int
i,k,s,j, $\lambda$ ,min,loc,maxinventory,noper,nodays,meandem,meanldtm,revtm,reorderlvl,bko
rcost[20],surpcost[20],demvar1,timvar1,demvar2,timvar2,di[15][15];
int temp,distcharge;
void thanku();
void sort(int x[],int n)
{
    int i,j, temp;
    for(i=0;i<n-1;i++)
        for(j=i+1;j<n;j++)
            {
                if(x[i]> x[j])
                {
                    temp=x[i];
                    x[i]=x[j];
                    x[j]=temp;
                }
            }
    return;
}
}
class inventory
{
    int sno;
    int demand;
    int inhaninventory_start ;
    int inventoryreached_day;
    int totalinventory_start;
    int surplusquantity;
    int stockoutquantity;
    int orderedquantity;
    int leadtime;
    int recievingday_inventory;
    int intransitinventory;
    int demandsatisfied;
    int totaldemand;
    int noofperioodelivered;
    int totalperiod;
    int transcost;
```

```

public:
    inventory()
    {

        sno=0;
        demand=0;
        inhaninventory_start =0;
        inventoryreached_day=0;
        totalinventory_start=0;
        surplusquantity=0;
        stockoutquantity=0;
        orderedquantity=0;
        leadtime=0;
        recievingday_inventory=0;
        intransitinventory=0;
        demandsatisfied=0;
        totaldemand=0;
        noofperioddelivered=0;
        totalperiod=0;
        transcost=0;
//
    }
    void input();
    void adjust();
    void display()
    {
        cout<<"Product Type: "<<λ<<endl;
        cout<<"Day no: "<<sno<<endl;
        cout<<"Demand: "<<demand<<endl;
        cout<<"Inhand inventory at start: "<<inhaninventory_start<<endl;
        cout<<"Inventory reached at theday: "<<inventoryreached_day<<endl;
        cout<<"Total inventory at start: "<<totalinventory_start<<endl;
        cout<<"Surplus: "<<surplusquantity<<endl;
        cout<<"Stockout: "<<stockoutquantity<<endl;
        cout<<"Ordered quantity: "<<orderedquantity<<endl;
        cout<<"Lead-time: "<<leadtime<<endl;
        cout<<"Inventory recieving Day: "<<recievingday_inventory<<endl;
        cout<<"Intransitinventory: "<<intransitinventory<<endl;
        cout<<"Holding cost : Rs."<<surplusquantity*surpcost[k]<<endl;
        cout<<"Backorder cost : Rs."<<stockoutquantity*bkorcost[k]<<endl;
        cout<<"Transshipment Cost : Rs."<<transcost*distcharge<<endl;
        cout<<"Demand Satisfaction
Level"<<demandsatisfied/totaldemand<<endl;
        cout<<"Period Satisfaction
Level"<<noofperioddelivered/totalperiod<<endl;

        cout<<"\n-----";
    }
};

```

```

    }
    void final();
    void testy();

}inventory_arr[SIZE][SIZE];

void inventory :: input()
{
    if(i==0)
    {
        cout<<"ENTER STARTING INVENTORY    ";
        cin>>inhaninventory_start;
        cout<<"ENTER PRODUCT TYPE:";
        cin>>λ;
    }

    cout<<"\nEnter the Demand (b/w "<<demvar1<<" and
"<<demvar2<<"): ";
    do
    {
        cin>>demand;
        if((demand<demvar1) || (demand>demvar2))
            cout<<"\nInvalid value, please re-enter the demand
(b/w "<<demvar1<<" and "<<demvar2<<"): ";
    } while((demand<demvar1) || (demand>demvar2));
    cout<<"\nEnter the Demand Satisfied";
    cin>>demandsatisfied;
    cout<<"\nEnter the Total Demand";
    cin>>totaldemand;
    cout<<"\nEnter the No Of Period Delivered";
    cin>>noofperioddelivered;
    cout<<"\nEnter the Total Period";
    cin>>totalperiod;
    cout<<"\nEnter the Lead-time (b/w "<<timvar1<<" and
"<<timvar2<<"): ";
    do
    {
        cin>>leadtime ;
        if((leadtime<timvar1) || (leadtime>timvar2))
            cout<<"\nInvalid value, please re-enter the Lead-time
(b/w "<<timvar1<<" and "<<timvar2<<"): ";
    } while((leadtime<timvar1) || (leadtime>timvar2));
    totalinventory_start=inhaninventory_start+inventoryreached_day;
    surplusquantity=totalinventory_start-demand;
    if(surplusquantity >= 0)

```

```

        stockoutquantity=0;
    else
    {
        stockoutquantity= -(surplusquantity);
        surplusquantity=0;
    }
}
void inventory :: adjust()
{
for(int y=0;y<3;y++)
    for(int z=0;z<nodays;z++)
    {
        int s1=inventory_arr[0][z].surplusquantity;
        int s2=inventory_arr[1][z].surplusquantity;
        int s3=inventory_arr[2][z].surplusquantity;
        int arr[]={s1,s2,s3};
        sort(arr,3);
        if(arr[0]<0 || arr[1]<0 || arr[2]<0)
        {
            if(arr[0]<0)
            {
                int temp=-arr[0];
                if(arr[2]>temp)
                {
                    arr[2]-=temp;
                    arr[0]=0;
                }
                else
                {
                    int temp2=temp-arr[2];
                    arr[2]=0;
                    arr[1]-=temp2;
                    arr[0]=0;
                }
            }
            if (arr[0] <0)
            arr[0]=0;
            if (arr[1] <0)
            arr[1]=0;
            if (arr[2] <0)
            arr[0]=0;
            inventory_arr[0][z].surplusquantity=arr[0];
            inventory_arr[1][z].surplusquantity=arr[1];
            inventory_arr[2][z].surplusquantity=arr[2];
        }
    }
}
if(surplusquantity>=reorderlvl)
    orderedquantity=0;

```

```

else
    orderedquantity=maxinventory-
(surplusquantity+intransitinventory);
    for(int j=1;j<=leadtime;j++)
        inventory_arr[k][i+j].intransitinventory+=orderedquantity;
    sno=i+1;
    recievingday_inventory=sno+1+leadtime ;
    inventory_arr[k][i+1].inhaninventory_start=surplusquantity;
    int x=sno+1+leadtime;
    if(inventory_arr[k][x-1].inventoryreached_day==0)
        inventory_arr[k][x-1].inventoryreached_day=orderedquantity;
    else
        inventory_arr[k][x-1].inventoryreached_day+=orderedquantity;
/*
    if(surplusquantity<0)
        surplusquantity=0;
    if(orderedquantity<0)
        orderedquantity=0;*/
}
void inventory :: testy()
{
int x,y,di_testy[15][15];
s=k;
for(x=0;x<15;x++)
{
    for(y=0;y<15;y++)
    {
        di_testy[x][y]=0;
    }
}
for(x=0;x<noper;x++)
{
    for(y=x+1;y<noper;y++)
    {
        di_testy[x][y]=di[x][y];
    }
    cout<<endl;
}
while(stockoutquantity>0)
{
min=di_testy[k][0];
if(min==0)
{
min=di_testy[k][1];
loc=1;
}
}

for(j=0;j<noper;j++)
{
if(di_testy[k][j]!=0)

```

```

{
    if(di_testy[k][j]<min)
    {
        min=di_testy[k][j];
        loc=j;
    }
}
}
if(min==0)
{
    return;
}
else
{
    temp=stockoutquantity;
    inventory_arr[loc][i].surplusquantity-=stockoutquantity;
    if(inventory_arr[loc][i].surplusquantity<0)
    {
        stockoutquantity=-(inventory_arr[loc][i].surplusquantity);
        inventory_arr[loc][i].surplusquantity=0;
        inventory_arr[loc][i+1].inhaninventory_start=0;
    }
    else
    {
        stockoutquantity=0;

        inventory_arr[loc][i+1].inhaninventory_start=inventory_arr[loc][i].surplusqua
ntity;
    }
    transcost=transcost+(temp-stockoutquantity);
}
/* else
{
    if(s==(noper-1))
    {
        do
        {
            cout<<"asfsdf"<<<inventory_arr[s-1][i].surplusquantity;
            inventory_arr[s-1][i].surplusquantity-=stockoutquantity;
            if(inventory_arr[s-1][i].surplusquantity<0)
            {
                stockoutquantity=-(inventory_arr[s-1][i].surplusquantity);
                inventory_arr[s-1][i].surplusquantity=0;
                inventory_arr[s-1][i+1].inhaninventory_start=0;
                s=s-1;
            }
        }
    }
}
}

```

```

        else
        {
            stockoutquantity=0;
            inventory_arr[s-1][i+1].inhaninventory_start=inventory_arr[s-
1][i].surplusquantity;
        }
    }while(s>=0 && stockoutquantity!=0) ;

    }
    else
    {

    }

}*/
di_testy[k][loc]=0;
}
}
void inventory :: final()
{
    cout<<“\n\t\t\tOVERVIEW”<<endl;
    int a,b,c,d,e,f,g;
    for(i=0;i<noper;i++)
    {
        a=0;
        b=0;
        c=0;
        d=0;
        e=0;
        f=0;
        g=0;
        for(int j=0;j<nodays;j++)
        {
            If( $\lambda$  == inventory_arr[i][j] )
            {
                c+=(inventory_arr[i][j].surplusquantity);
                d+=(inventory_arr[i][j].stockoutquantity);
                e+=(inventory_arr[i][j].totalinventory_start);
                f+=(inventory_arr[i][j].orderedquantity);
                a+=(inventory_arr[i][j].surplusquantity*surpcost[i]);
                b+=(inventory_arr[i][j].stockoutquantity*bkorcst[i]);
                g+=(inventory_arr[i][j].transcost);
            }
        }
        cout<<“\n\nRetailer “<<i+1<<endl;
        cout<<“\n\tTotal Surplus quantity : “<<c;
        cout<<“\n\tTotal StockOut quantity : “<<d;
        cout<<“\n\tTotal inventory at start : “<<e;
        cout<<“\n\tTotal ordered quantity : “<<f;
    }
}

```

```

        cout<<"\n\tTotal holding cost : Rs."<<a;
        cout<<"\n\tTotal backorder cost : Rs."<<b;
        cout<<"\n\tTotal cost : Rs."<<a+b;
        cout<<"\n\tTotal Transshipment Cost : Rs."<<g*distcharge;
    }
}

int main()
{
    int j,sdmd,sdlt,y;
//    clrscr();
    cout<<"-----INVENTORY SIMULATION MODEL-----
\n"<<endl;
    cout<<"Enter the desired product you want to check"
    cin>>λ;
    cout<<"Of how many days you want to keep the record: ";
    cin>>noday;
    cout<<"\nWhat is the mean Demand: ";
    cin>>meandem;
    cout<<"\nWhat is the standard deviation from mean Demand: ";
    cin>>sdmd;
    cout<<"\nWhat is the mean Lead-time: ";
    cin>>meanldtm;
    cout<<"\nWhat is the standard deviation from mean Lead-time: ";
    cin>>sdlt;
    cout<<"\nWhat is the per Kilometer Transshipment Cost: ";
    cin>>distcharge;
    demvar1=meandem-3*sdmd;
    timvar1=meanldtm-3*sdlt;
    demvar2=meandem+3*sdmd;
    timvar2=meanldtm+3*sdlt;
    if(demvar1<0)
        demvar1=0;
    if(demvar2<0)
        demvar2=0;
    if(timvar1<0)
        timvar1=0;
    if(timvar2<0)
        timvar2=0;
    cout<<"\nWhat is the Review Time: ";
    cin>>revtm;
    cout<<"\nEnter the number of retailers: ";
    cin>>noper;
    for(i=0;i<noper;i++)
    {
        for(k=i+1;k<noper;k++)
        {

```

```

        cout<<"ENTER THE DISTANCE bw RETAILER "<<i+1<<"
AND "<<k+1<<" .?";
        cin>>di[i][k];
        di[k][i]=di[i][k];
    }    cout<<endl;
}

for(k=0;k<noper;k++)
{
    cout<<"\nEnter the per unit backorder cost for retailer "<<k+1<<" : ";
    cin>>bkorcost[k];
    cout<<"\nEnter the per unit surplus cost for retailer "<<k+1<<" : ";
    cin>>surpcost[k];
}
maxinventory=(meanldtm+revtm)*meandem;
reorderlvl=meanldtm*meandem;
for(i=0;i<nodays;i++)
{
    for(k=0;k<noper;k++)
    {
        If(arr[i] ==  $\lambda$  || arr[k] ==  $\lambda$ )
        {
            cout<<"\n\nPlease enter the values for retailer
<<k+1<<" for day "<<i+1<<endl;
            inventory_arr[k][i].input();
            inventory_arr[k][i].adjust();
        }
    }
    for(k=0;k<noper;k++)
    {
        inventory_arr[k][i].testy();
    }
    cout<<endl;
}

int r,x;
cout<<"\nDo you want to see the result(y/n): ";
char choice;
cin>>choice;
if((choice=='n')||(choice=='N'))
    exit(0);

do
{
    cout<<"How u want to see the result \n1. Between two days \n2.
Specific day";
    int selection;
    cin>>selection;
}

```

```

if(selection==2)
{
    cout<< "\nFor which day u want to see the result: ";
    cin>>x;
    r=x-1;
//    clrscr();
    for(k=0;k<noper;k++)
    {
        j=k+1;
        if(j%3==0)
        {
            getch();
//            clrscr();
        }
        cout<< "\nThe values for retailer "<<k+1<<" are as follows:
\n";
        cout<<endl;
        inventory_arr[k][r].display();
    }
}
else
{
    cout<< "\nFrom which day to which day u want to see the result: ";
    cin>>x;
    r=x-1;
    cin>>y;
    y=y-1;
//    clrscr();
    for(;r<=y;r++)
    {
        for(k=0;k<noper;k++)
        {
            j=k+1;
            if(j%3==0)
            {
                getch();
//                clrscr();
            }
            cout<< "\nThe values for retailer "<<k+1<<" are as follows:
\n";
            cout<<endl;
            inventory_arr[k][r].display();
        }
    }
}

```

```

    }
        cout<<“\nDo you want to see the result again(y/n): “;
        cin>>choice;

    }while(choice==‘y’ || choice==‘Y’);
        inventory_arr[0][0].final();
        getch();
        thanku();
    }
void thanku()
{
// clrscr();
char t[]=“!!!!!!!!THANK YOU!!!!!!!!”;
// gotoxy(25,15);
for(int i=0;i<strlen(t);i++)
{
// delay(50);
cout<<t[i];
}
getch();
}

```

APPENDIX – C

**Total Inventory Available and Demand Without Transshipment (Maruti Suzuki India Limited)**

| Day | In-hand Inventory |   |   | Demand |   |   |    | In-hand Inventory |    |   | Demand |   |   |    | In-hand Inventory |          |   | Demand |   |   |    | In-hand Inventory |   |          | Demand |   |   |
|-----|-------------------|---|---|--------|---|---|----|-------------------|----|---|--------|---|---|----|-------------------|----------|---|--------|---|---|----|-------------------|---|----------|--------|---|---|
|     | B                 | R | S | B      | R | S |    | Feb., 09          | B  | R | S      | B | R |    | S                 | Mar., 09 | B | R      | S | B |    | R                 | S | Apr., 09 | B      | R | S |
| 1   | 4                 | 0 | 0 | 0      | 1 | 0 | 1  | 4                 | 7  | 4 | 0      | 0 | 1 | 1  | 6                 | 10       | 6 | 2      | 1 | 1 | 1  | 4                 | 5 | 5        | 1      | 1 | 0 |
| 2   | 4                 | 0 | 0 | 1      | 0 | 1 | 2  | 4                 | 7  | 3 | 1      | 0 | 2 | 2  | 4                 | 9        | 5 | 1      | 0 | 1 | 2  | 3                 | 4 | 5        | 0      | 2 | 1 |
| 3   | 4                 | 0 | 2 | 0      | 0 | 0 | 3  | 3                 | 8  | 1 | 0      | 0 | 2 | 3  | 3                 | 9        | 4 | 0      | 0 | 2 | 3  | 3                 | 2 | 4        | 2      | 1 | 0 |
| 4   | 4                 | 1 | 2 | 0      | 0 | 1 | 4  | 3                 | 8  | 0 | 0      | 0 | 0 | 4  | 7                 | 9        | 2 | 0      | 1 | 1 | 4  | 1                 | 1 | 4        | 2      | 2 | 0 |
| 5   | 4                 | 1 | 1 | 1      | 1 | 0 | 5  | 3                 | 8  | 2 | 1      | 2 | 0 | 5  | 7                 | 8        | 1 | 1      | 1 | 2 | 5  | 3                 | 2 | 4        | 0      | 0 | 1 |
| 6   | 3                 | 0 | 3 | 1      | 1 | 0 | 6  | 5                 | 9  | 2 | 0      | 0 | 0 | 6  | 6                 | 7        | 3 | 0      | 2 | 0 | 6  | 3                 | 2 | 3        | 0      | 1 | 0 |
| 7   | 2                 | 1 | 3 | 2      | 0 | 0 | 7  | 9                 | 9  | 2 | 0      | 1 | 1 | 7  | 6                 | 5        | 3 | 2      | 0 | 0 | 7  | 3                 | 1 | 5        | 0      | 2 | 1 |
| 8   | 0                 | 1 | 3 | 1      | 0 | 1 | 8  | 9                 | 9  | 1 | 0      | 0 | 2 | 8  | 4                 | 5        | 5 | 0      | 2 | 1 | 8  | 3                 | 4 | 4        | 1      | 0 | 1 |
| 9   | 3                 | 2 | 2 | 0      | 1 | 0 | 9  | 9                 | 10 | 0 | 0      | 0 | 0 | 9  | 7                 | 3        | 4 | 1      | 1 | 0 | 9  | 2                 | 4 | 3        | 1      | 1 | 1 |
| 10  | 3                 | 2 | 4 | 0      | 0 | 1 | 10 | 9                 | 10 | 0 | 1      | 0 | 0 | 10 | 6                 | 2        | 4 | 0      | 2 | 1 | 10 | 1                 | 3 | 2        | 2      | 0 | 0 |
| 11  | 3                 | 2 | 3 | 0      | 0 | 0 | 11 | 8                 | 10 | 2 | 1      | 0 | 0 | 11 | 6                 | 0        | 3 | 1      | 1 | 0 | 11 | 4                 | 3 | 4        | 0      | 0 | 0 |
| 12  | 3                 | 2 | 3 | 1      | 1 | 1 | 12 | 7                 | 11 | 2 | 2      | 1 | 0 | 12 | 5                 | 4        | 5 | 0      | 0 | 1 | 12 | 4                 | 3 | 4        | 0      | 0 | 1 |
| 13  | 2                 | 1 | 2 | 0      | 0 | 1 | 13 | 5                 | 10 | 3 | 0      | 3 | 0 | 13 | 5                 | 4        | 4 | 1      | 0 | 1 | 13 | 4                 | 5 | 3        | 1      | 1 | 0 |
| 14  | 2                 | 4 | 1 | 1      | 0 | 1 | 14 | 5                 | 7  | 3 | 1      | 0 | 1 | 14 | 4                 | 4        | 6 | 2      | 1 | 0 | 14 | 3                 | 4 | 5        | 0      | 1 | 0 |
| 15  | 1                 | 4 | 3 | 2      | 0 | 0 | 15 | 4                 | 7  | 2 | 0      | 2 | 0 | 15 | 2                 | 5        | 6 | 1      | 0 | 0 | 15 | 3                 | 3 | 5        | 2      | 0 | 0 |
| 16  | 0                 | 5 | 3 | 0      | 0 | 0 | 16 | 5                 | 5  | 2 | 2      | 0 | 1 | 16 | 1                 | 5        | 6 | 2      | 2 | 1 | 16 | 1                 | 3 | 5        | 2      | 2 | 0 |
| 17  | 6                 | 5 | 3 | 0      | 1 | 0 | 17 | 3                 | 5  | 1 | 0      | 0 | 2 | 17 | 4                 | 3        | 6 | 0      | 0 | 2 | 17 | 6                 | 3 | 5        | 0      | 0 | 2 |
| 18  | 6                 | 4 | 4 | 0      | 0 | 1 | 18 | 3                 | 5  | 4 | 1      | 2 | 0 | 18 | 4                 | 3        | 4 | 1      | 0 | 0 | 18 | 6                 | 3 | 3        | 1      | 0 | 1 |
| 19  | 6                 | 4 | 3 | 2      | 1 | 1 | 19 | 2                 | 3  | 4 | 0      | 0 | 0 | 19 | 3                 | 5        | 4 | 0      | 1 | 0 | 19 | 5                 | 3 | 4        | 0      | 0 | 0 |
| 20  | 4                 | 3 | 2 | 2      | 1 | 0 | 20 | 2                 | 3  | 4 | 1      | 1 | 0 | 20 | 3                 | 4        | 4 | 0      | 2 | 1 | 20 | 5                 | 3 | 4        | 0      | 2 | 1 |
| 21  | 2                 | 6 | 3 | 0      | 0 | 0 | 21 | 3                 | 2  | 4 | 0      | 1 | 1 | 21 | 7                 | 2        | 5 | 1      | 1 | 0 | 21 | 5                 | 1 | 3        | 1      | 1 | 0 |
| 22  | 2                 | 6 | 3 | 1      | 0 | 2 | 22 | 3                 | 1  | 3 | 0      | 1 | 1 | 22 | 6                 | 1        | 5 | 0      | 2 | 1 | 22 | 4                 | 0 | 3        | 0      | 1 | 1 |
| 23  | 1                 | 6 | 1 | 2      | 2 | 0 | 23 | 6                 | 0  | 5 | 0      | 1 | 0 | 23 | 6                 | 3        | 4 | 0      | 0 | 0 | 23 | 3                 | 2 | 6        | 1      | 0 | 1 |
| 24  | 0                 | 4 | 2 | 0      | 0 | 0 | 24 | 7                 | 6  | 5 | 0      | 0 | 0 | 24 | 6                 | 3        | 4 | 1      | 0 | 1 | 24 | 4                 | 2 | 5        | 0      | 0 | 0 |
| 25  | 0                 | 7 | 2 | 0      | 0 | 0 | 25 | 7                 | 11 | 5 | 0      | 0 | 0 | 25 | 5                 | 5        | 3 | 0      | 0 | 0 | 25 | 4                 | 5 | 5        | 1      | 1 | 0 |
| 26  | 6                 | 7 | 2 | 0      | 0 | 1 | 26 | 7                 | 11 | 5 | 1      | 0 | 0 | 26 | 5                 | 5        | 6 | 1      | 0 | 0 | 26 | 3                 | 4 | 5        | 0      | 0 | 2 |
| 27  | 6                 | 7 | 1 | 0      | 1 | 0 | 27 | 6                 | 11 | 7 | 0      | 1 | 0 | 27 | 4                 | 5        | 6 | 0      | 2 | 1 | 27 | 3                 | 4 | 5        | 1      | 0 | 0 |
| 28  | 6                 | 6 | 1 | 0      | 2 | 2 | 28 | 7                 | 10 | 7 | 1      | 0 | 1 | 28 | 6                 | 3        | 5 | 1      | 0 | 0 | 28 | 6                 | 4 | 5        | 0      | 0 | 0 |
| 29  | 6                 | 4 | 4 | 0      | 0 | 0 |    |                   |    |   |        |   |   | 29 | 5                 | 3        | 5 | 0      | 0 | 0 | 29 | 6                 | 4 | 7        | 1      | 0 | 1 |
| 30  | 6                 | 7 | 4 | 0      | 0 | 0 |    |                   |    |   |        |   |   | 30 | 5                 | 5        | 6 | 1      | 0 | 1 | 30 | 5                 | 4 | 6        | 0      | 1 | 0 |
| 31  | 6                 | 7 | 4 | 2      | 0 | 0 |    |                   |    |   |        |   |   | 31 | 4                 | 5        | 5 | 0      | 0 | 0 |    |                   |   |          |        |   |   |

APPENDIX – D

**Total Inventory Available and Demand Without Transshipment (Bajaj Auto Limited)**

| In-hand inventory | January, 09 |    |    |    |    | February, 09 |    |    |    |    | March, 09 |    |    |    |    | April, 09 |    |    |    |    | May, 09 |    |    |    |    | June, 09 |    |    |    |    |
|-------------------|-------------|----|----|----|----|--------------|----|----|----|----|-----------|----|----|----|----|-----------|----|----|----|----|---------|----|----|----|----|----------|----|----|----|----|
|                   | J           | K  | B  | R  | H  | J            | K  | B  | R  | H  | J         | K  | B  | R  | H  | J         | K  | B  | R  | H  | J       | K  | B  | R  | H  | J        | K  | B  | R  | H  |
| 1                 | 12          | 15 | 8  | 14 | 10 | 14           | 16 | 2  | 10 | 17 | 15        | 11 | 2  | 10 | 14 | 13        | 10 | 19 | 7  | 2  | 11      | 9  | 7  | 10 | 12 | 5        | 14 | 15 | 13 | 8  |
| 2                 | 10          | 15 | 5  | 13 | 5  | 13           | 16 | 0  | 8  | 16 | 14        | 9  | 0  | 9  | 12 | 12        | 8  | 19 | 5  | 0  | 18      | 7  | 7  | 9  | 11 | 3        | 13 | 14 | 12 | 6  |
| 3                 | 9           | 14 | 1  | 11 | 11 | 11           | 15 | 8  | 7  | 14 | 14        | 6  | 0  | 9  | 11 | 12        | 7  | 19 | 4  | 0  | 16      | 6  | 5  | 9  | 10 | 0        | 11 | 14 | 11 | 3  |
| 4                 | 5           | 12 | 0  | 9  | 8  | 10           | 14 | 7  | 4  | 13 | 13        | 4  | 15 | 17 | 11 | 10        | 4  | 18 | 4  | 16 | 16      | 2  | 2  | 8  | 10 | 19       | 7  | 14 | 11 | 1  |
| 5                 | 2           | 11 | 10 | 14 | 7  | 8            | 13 | 15 | 2  | 11 | 11        | 1  | 15 | 17 | 10 | 10        | 2  | 18 | 2  | 16 | 14      | 0  | 0  | 6  | 8  | 18       | 5  | 12 | 8  | 0  |
| 6                 | 0           | 9  | 10 | 13 | 5  | 7            | 12 | 15 | 0  | 18 | 9         | 0  | 14 | 15 | 9  | 9         | 0  | 18 | 1  | 16 | 13      | 16 | 9  | 5  | 8  | 18       | 2  | 11 | 15 | 16 |
| 7                 | 16          | 8  | 9  | 11 | 3  | 3            | 12 | 14 | 0  | 14 | 8         | 11 | 14 | 14 | 6  | 6         | 15 | 18 | 0  | 15 | 13      | 16 | 8  | 3  | 7  | 16       | 1  | 8  | 13 | 16 |
| 8                 | 15          | 4  | 8  | 10 | 0  | 1            | 10 | 13 | 15 | 13 | 5         | 11 | 13 | 14 | 4  | 4         | 15 | 18 | 8  | 13 | 11      | 16 | 8  | 2  | 7  | 13       | 0  | 6  | 12 | 16 |
| 9                 | 13          | 1  | 14 | 10 | 15 | 15           | 9  | 13 | 15 | 12 | 3         | 10 | 12 | 13 | 1  | 0         | 13 | 18 | 8  | 12 | 10      | 15 | 8  | 0  | 6  | 13       | 12 | 2  | 10 | 15 |
| 10                | 12          | 0  | 14 | 9  | 15 | 14           | 7  | 12 | 14 | 10 | 0         | 8  | 10 | 11 | 0  | 18        | 13 | 18 | 7  | 12 | 8       | 15 | 8  | 0  | 4  | 11       | 12 | 0  | 10 | 15 |
| 11                | 10          | 17 | 13 | 6  | 15 | 13           | 4  | 12 | 14 | 7  | 0         | 7  | 10 | 10 | 12 | 18        | 13 | 18 | 7  | 10 | 4       | 14 | 8  | 18 | 3  | 10       | 11 | 0  | 8  | 12 |
| 12                | 9           | 15 | 13 | 4  | 14 | 11           | 0  | 1  | 13 | 5  | 16        | 7  | 9  | 10 | 12 | 17        | 11 | 17 | 19 | 10 | 1       | 12 | 6  | 18 | 1  | 10       | 11 | 14 | 7  | 10 |
| 13                | 5           | 15 | 11 | 2  | 13 | 10           | 8  | 9  | 11 | 5  | 16        | 4  | 8  | 6  | 11 | 16        | 10 | 17 | 19 | 9  | 0       | 12 | 5  | 17 | 0  | 9        | 11 | 14 | 3  | 9  |
| 14                | 3           | 12 | 15 | 15 | 13 | 10           | 7  | 8  | 10 | 2  | 15        | 2  | 16 | 3  | 11 | 16        | 6  | 16 | 19 | 7  | 8       | 11 | 5  | 17 | 8  | 9        | 11 | 13 | 0  | 18 |
| 15                | 2           | 12 | 15 | 15 | 12 | 6            | 5  | 8  | 9  | 0  | 15        | 17 | 16 | 1  | 9  | 15        | 5  | 14 | 18 | 7  | 8       | 11 | 3  | 15 | 8  | 18       | 9  | 13 | 0  | 18 |
| 16                | 0           | 9  | 14 | 15 | 9  | 15           | 16 | 16 | 9  | 18 | 14        | 16 | 15 | 0  | 8  | 15        | 3  | 14 | 18 | 4  | 17      | 20 | 1  | 14 | 6  | 18       | 8  | 13 | 0  | 17 |
| 17                | 18          | 7  | 13 | 14 | 18 | 15           | 15 | 15 | 7  | 18 | 13        | 16 | 14 | 14 | 6  | 14        | 1  | 14 | 17 | 2  | 17      | 19 | 1  | 14 | 20 | 17       | 18 | 11 | 15 | 17 |
| 18                | 17          | 4  | 13 | 13 | 18 | 14           | 15 | 14 | 6  | 17 | 11        | 15 | 14 | 13 | 3  | 12        | 10 | 14 | 17 | 1  | 17      | 19 | 0  | 11 | 20 | 17       | 18 | 18 | 14 | 15 |
| 19                | 15          | 2  | 12 | 11 | 17 | 12           | 12 | 14 | 4  | 16 | 11        | 13 | 12 | 13 | 1  | 12        | 9  | 14 | 16 | 0  | 16      | 18 | 0  | 11 | 18 | 16       | 18 | 18 | 14 | 15 |
| 20                | 14          | 0  | 10 | 11 | 17 | 12           | 11 | 13 | 0  | 14 | 18        | 13 | 11 | 13 | 0  | 11        | 9  | 14 | 16 | 0  | 15      | 18 | 4  | 9  | 17 | 16       | 15 | 17 | 14 | 14 |
| 21                | 14          | 19 | 9  | 10 | 15 | 11           | 9  | 12 | 15 | 13 | 16        | 12 | 11 | 13 | 10 | 8         | 8  | 13 | 16 | 16 | 15      | 16 | 4  | 9  | 17 | 15       | 14 | 15 | 13 | 12 |
| 22                | 13          | 19 | 9  | 9  | 14 | 10           | 8  | 11 | 15 | 12 | 15        | 10 | 10 | 10 | 9  | 18        | 16 | 12 | 16 | 16 | 14      | 15 | 3  | 8  | 15 | 15       | 14 | 15 | 11 | 12 |
| 23                | 13          | 19 | 9  | 7  | 13 | 8            | 8  | 11 | 15 | 11 | 13        | 17 | 10 | 9  | 9  | 17        | 16 | 12 | 15 | 16 | 13      | 12 | 2  | 8  | 15 | 14       | 14 | 14 | 10 | 11 |
| 24                | 12          | 18 | 7  | 17 | 13 | 7            | 18 | 9  | 14 | 9  | 13        | 16 | 7  | 9  | 8  | 17        | 14 | 10 | 13 | 16 | 13      | 10 | 19 | 7  | 14 | 11       | 13 | 12 | 9  | 9  |
| 25                | 10          | 18 | 6  | 16 | 11 | 5            | 17 | 8  | 14 | 9  | 12        | 16 | 5  | 13 | 8  | 16        | 13 | 9  | 13 | 15 | 11      | 9  | 19 | 6  | 11 | 10       | 13 | 11 | 15 | 9  |
| 26                | 9           | 15 | 6  | 16 | 11 | 2            | 15 | 7  | 13 | 17 | 10        | 15 | 4  | 13 | 6  | 16        | 13 | 8  | 12 | 15 | 10      | 9  | 19 | 16 | 11 | 10       | 11 | 11 | 13 | 17 |
| 27                | 17          | 14 | 4  | 16 | 20 | 0            | 12 | 5  | 13 | 16 | 9         | 13 | 1  | 12 | 5  | 15        | 13 | 8  | 12 | 15 | 10      | 9  | 18 | 16 | 11 | 9        | 10 | 10 | 13 | 16 |
| 28                | 17          | 12 | 3  | 15 | 19 | 15           | 12 | 4  | 11 | 16 | 9         | 13 | 1  | 11 | 3  | 13        | 10 | 8  | 12 | 15 | 10      | 8  | 18 | 16 | 11 | 9        | 10 | 9  | 12 | 14 |
| 29                | 16          | 11 | 3  | 15 | 19 |              |    |    |    |    | 15        | 13 | 0  | 9  | 3  | 12        | 9  | 8  | 11 | 13 | 8       | 16 | 16 | 15 | 11 | 7        | 10 | 9  | 12 | 14 |
| 30                | 16          | 9  | 3  | 14 | 18 |              |    |    |    |    | 14        | 12 | 19 | 9  | 3  | 11        | 9  | 7  | 11 | 12 | 8       | 15 | 16 | 15 | 9  | 6        | 10 | 18 | 11 | 13 |
| 31                | 15          | 16 | 2  | 14 | 18 |              |    |    |    |    | 14        | 10 | 19 | 8  | 2  |           |    |    |    |    | 7       | 15 | 15 | 15 | 8  |          |    |    |    |    |

| Demand | January, 09 |   |   |   |   | February, 09 |   |   |   |   | March, 09 |   |   |   |   | April, 09 |   |   |   |   | May, 09 |   |   |   |   | June, 09 |   |   |   |   |   |
|--------|-------------|---|---|---|---|--------------|---|---|---|---|-----------|---|---|---|---|-----------|---|---|---|---|---------|---|---|---|---|----------|---|---|---|---|---|
| 1      | 2           | 0 | 3 | 1 | 2 | 1            | 0 | 3 | 2 | 1 | 1         | 2 | 2 | 1 | 2 | 1         | 2 | 0 | 2 | 2 | 1       | 2 | 0 | 1 | 1 | 2        | 1 | 1 | 1 | 1 | 2 |
| 2      | 1           | 1 | 4 | 2 | 2 | 2            | 1 | 2 | 1 | 2 | 0         | 3 | 1 | 0 | 1 | 0         | 1 | 0 | 1 | 1 | 2       | 1 | 2 | 0 | 1 | 4        | 2 | 0 | 1 | 3 |   |
| 3      | 4           | 2 | 3 | 2 | 3 | 1            | 1 | 1 | 3 | 1 | 1         | 2 | 2 | 2 | 0 | 2         | 3 | 1 | 0 | 2 | 0       | 4 | 3 | 1 | 0 | 2        | 4 | 0 | 0 | 2 |   |
| 4      | 3           | 1 | 2 | 1 | 1 | 2            | 1 | 2 | 2 | 2 | 2         | 3 | 0 | 0 | 1 | 0         | 2 | 0 | 2 | 0 | 2       | 2 | 3 | 2 | 2 | 1        | 2 | 2 | 3 | 2 |   |
| 5      | 3           | 2 | 0 | 1 | 2 | 1            | 1 | 0 | 3 | 1 | 2         | 2 | 1 | 2 | 1 | 1         | 3 | 0 | 1 | 0 | 1       | 1 | 2 | 1 | 0 | 0        | 3 | 1 | 0 | 1 |   |
| 6      | 2           | 1 | 1 | 2 | 2 | 4            | 0 | 1 | 2 | 4 | 1         | 1 | 0 | 1 | 3 | 3         | 1 | 0 | 2 | 1 | 0       | 0 | 1 | 2 | 1 | 2        | 1 | 3 | 2 | 0 |   |
| 7      | 1           | 4 | 1 | 1 | 4 | 2            | 2 | 1 | 1 | 1 | 3         | 0 | 1 | 0 | 2 | 2         | 0 | 0 | 2 | 2 | 2       | 0 | 0 | 1 | 0 | 3        | 2 | 2 | 1 | 0 |   |
| 8      | 2           | 3 | 2 | 0 | 2 | 2            | 1 | 0 | 0 | 1 | 2         | 1 | 1 | 1 | 3 | 4         | 2 | 0 | 0 | 1 | 1       | 1 | 0 | 3 | 1 | 0        | 1 | 4 | 2 | 1 |   |
| 9      | 1           | 2 | 0 | 1 | 0 | 1            | 2 | 1 | 1 | 2 | 3         | 2 | 2 | 2 | 2 | 2         | 0 | 0 | 1 | 0 | 2       | 0 | 0 | 1 | 2 | 2        | 0 | 2 | 0 | 0 |   |
| 10     | 2           | 2 | 1 | 3 | 0 | 1            | 3 | 0 | 0 | 3 | 1         | 1 | 0 | 1 | 1 | 0         | 0 | 0 | 0 | 2 | 4       | 1 | 0 | 1 | 1 | 1        | 1 | 3 | 2 | 3 |   |
| 11     | 1           | 2 | 0 | 2 | 1 | 2            | 4 | 1 | 1 | 2 | 2         | 0 | 1 | 0 | 0 | 1         | 2 | 1 | 2 | 0 | 3       | 2 | 2 | 0 | 2 | 0        | 0 | 1 | 1 | 2 |   |
| 12     | 4           | 0 | 2 | 2 | 1 | 1            | 2 | 2 | 2 | 0 | 0         | 3 | 1 | 4 | 1 | 1         | 1 | 0 | 0 | 1 | 2       | 0 | 1 | 1 | 3 | 1        | 0 | 0 | 4 | 1 |   |
| 13     | 2           | 3 | 2 | 3 | 0 | 0            | 1 | 1 | 1 | 3 | 1         | 2 | 2 | 3 | 0 | 0         | 4 | 1 | 0 | 2 | 3       | 1 | 0 | 0 | 1 | 0        | 0 | 1 | 3 | 1 |   |
| 14     | 1           | 0 | 0 | 0 | 1 | 4            | 2 | 0 | 1 | 3 | 0         | 3 | 0 | 2 | 2 | 1         | 1 | 2 | 1 | 0 | 0       | 0 | 2 | 2 | 0 | 1        | 2 | 0 | 2 | 0 |   |
| 15     | 3           | 3 | 1 | 0 | 3 | 3            | 1 | 2 | 0 | 1 | 1         | 1 | 1 | 3 | 1 | 0         | 2 | 0 | 0 | 3 | 1       | 2 | 2 | 1 | 2 | 0        | 1 | 0 | 1 | 1 |   |
| 16     | 1           | 2 | 1 | 1 | 1 | 0            | 1 | 1 | 2 | 0 | 1         | 0 | 1 | 1 | 2 | 1         | 2 | 0 | 1 | 2 | 0       | 1 | 0 | 0 | 1 | 1        | 2 | 2 | 3 | 0 |   |
| 17     | 1           | 3 | 0 | 1 | 0 | 1            | 0 | 1 | 1 | 1 | 2         | 1 | 0 | 1 | 3 | 2         | 2 | 0 | 0 | 1 | 0       | 0 | 2 | 3 | 0 | 0        | 0 | 1 | 1 | 2 |   |
| 18     | 2           | 2 | 1 | 2 | 1 | 2            | 3 | 0 | 2 | 1 | 0         | 2 | 2 | 0 | 2 | 0         | 1 | 0 | 1 | 2 | 1       | 1 | 1 | 0 | 2 | 1        | 0 | 0 | 0 | 0 |   |
| 19     | 1           | 3 | 2 | 0 | 0 | 0            | 1 | 1 | 4 | 2 | 1         | 0 | 1 | 0 | 2 | 1         | 0 | 0 | 0 | 1 | 1       | 0 | 0 | 2 | 1 | 0        | 3 | 1 | 0 | 1 |   |
| 20     | 0           | 2 | 1 | 1 | 2 | 1            | 2 | 1 | 2 | 1 | 2         | 1 | 0 | 0 | 2 | 3         | 1 | 1 | 0 | 2 | 0       | 2 | 0 | 0 | 0 | 1        | 1 | 2 | 1 | 2 |   |
| 21     | 1           | 0 | 0 | 1 | 1 | 1            | 1 | 1 | 0 | 1 | 1         | 2 | 1 | 3 | 1 | 0         | 1 | 1 | 0 | 0 | 1       | 1 | 1 | 1 | 1 | 2        | 0 | 0 | 2 | 0 |   |
| 22     | 0           | 0 | 0 | 2 | 1 | 2            | 0 | 0 | 0 | 1 | 2         | 3 | 0 | 1 | 0 | 1         | 0 | 0 | 1 | 0 | 1       | 3 | 1 | 0 | 0 | 1        | 0 | 1 | 1 | 1 |   |
| 23     | 1           | 1 | 2 | 0 | 0 | 1            | 0 | 2 | 1 | 2 | 0         | 1 | 3 | 0 | 1 | 0         | 2 | 2 | 2 | 0 | 0       | 2 | 3 | 1 | 1 | 3        | 1 | 2 | 1 | 2 |   |
| 24     | 2           | 0 | 1 | 1 | 2 | 2            | 1 | 1 | 0 | 0 | 1         | 0 | 2 | 2 | 0 | 1         | 1 | 1 | 0 | 1 | 2       | 1 | 0 | 1 | 3 | 1        | 0 | 1 | 0 | 0 |   |
| 25     | 1           | 3 | 0 | 0 | 0 | 3            | 2 | 1 | 1 | 2 | 2         | 1 | 1 | 0 | 2 | 0         | 0 | 1 | 1 | 0 | 1       | 0 | 0 | 2 | 0 | 0        | 2 | 0 | 2 | 2 |   |
| 26     | 2           | 1 | 2 | 0 | 1 | 4            | 3 | 2 | 0 | 1 | 1         | 2 | 3 | 1 | 1 | 1         | 0 | 0 | 0 | 0 | 0       | 0 | 1 | 0 | 0 | 1        | 1 | 1 | 0 | 1 |   |
| 27     | 0           | 2 | 1 | 1 | 1 | 1            | 0 | 1 | 2 | 0 | 0         | 0 | 0 | 1 | 2 | 2         | 3 | 0 | 0 | 0 | 0       | 1 | 0 | 0 | 0 | 0        | 0 | 1 | 1 | 2 |   |
| 28     | 1           | 1 | 0 | 0 | 0 | 0            | 1 | 2 | 1 | 2 | 2         | 0 | 1 | 2 | 0 | 1         | 1 | 0 | 1 | 2 | 2       | 2 | 2 | 1 | 0 | 2        | 0 | 0 | 0 | 0 |   |
| 29     | 0           | 2 | 0 | 1 | 1 |              |   |   |   |   | 1         | 1 | 2 | 0 | 0 | 1         | 0 | 1 | 0 | 1 | 0       | 1 | 0 | 0 | 2 | 1        | 0 | 1 | 1 | 1 |   |
| 30     | 1           | 1 | 1 | 0 | 0 |              |   |   |   |   | 0         | 2 | 0 | 1 | 1 | 0         | 0 | 0 | 1 | 0 | 1       | 0 | 1 | 0 | 1 | 0        | 2 | 2 | 1 | 1 |   |
| 31     | 1           | 0 | 0 | 4 | 1 |              |   |   |   |   | 1         | 0 | 0 | 1 | 0 |           |   |   |   |   | 2       | 1 | 0 | 2 | 0 |          |   |   |   |   |   |

APPENDIX – E

**Total Inventory Available and Demand Without Transshipment (Hero Honda Motors Limited)**

| In-hand inventory | May, 09 |    |    |    | June, 09 |    |    |    | July, 09 |    |    |    | August, 09 |    |    |    | September, 09 |    |    |    |
|-------------------|---------|----|----|----|----------|----|----|----|----------|----|----|----|------------|----|----|----|---------------|----|----|----|
|                   | D       | B  | R  | S  | D        | B  | R  | S  | D        | B  | R  | S  | D          | B  | R  | S  | D             | B  | R  | S  |
| 1                 | 13      | 5  | 17 | 3  | 18       | 8  | 24 | 16 | 21       | 17 | 23 | 3  | 26         | 4  | 18 | 18 | 21            | 19 | 19 | 18 |
| 2                 | 13      | 3  | 16 | 0  | 17       | 4  | 22 | 13 | 19       | 12 | 20 | 0  | 24         | 1  | 18 | 29 | 21            | 19 | 14 | 17 |
| 3                 | 12      | 2  | 16 | 18 | 17       | 0  | 21 | 12 | 19       | 10 | 31 | 26 | 24         | 0  | 25 | 27 | 20            | 18 | 8  | 28 |
| 4                 | 12      | 0  | 15 | 18 | 17       | 25 | 21 | 8  | 18       | 4  | 31 | 25 | 23         | 22 | 24 | 26 | 20            | 18 | 4  | 27 |
| 5                 | 12      | 24 | 14 | 16 | 15       | 25 | 21 | 3  | 18       | 0  | 29 | 25 | 23         | 22 | 23 | 23 | 20            | 18 | 4  | 27 |
| 6                 | 10      | 24 | 14 | 15 | 14       | 24 | 20 | 1  | 17       | 27 | 25 | 23 | 23         | 22 | 21 | 23 | 20            | 30 | 3  | 27 |
| 7                 | 16      | 22 | 11 | 15 | 14       | 24 | 20 | 0  | 29       | 26 | 25 | 23 | 23         | 19 | 21 | 22 | 20            | 30 | 3  | 27 |
| 8                 | 15      | 21 | 9  | 14 | 13       | 22 | 20 | 18 | 29       | 26 | 25 | 23 | 22         | 19 | 20 | 20 | 19            | 30 | 1  | 27 |
| 9                 | 15      | 20 | 28 | 14 | 12       | 22 | 18 | 18 | 27       | 26 | 24 | 22 | 22         | 19 | 31 | 20 | 19            | 29 | 0  | 27 |
| 10                | 15      | 20 | 27 | 10 | 8        | 21 | 18 | 17 | 27       | 25 | 24 | 22 | 21         | 19 | 31 | 20 | 29            | 29 | 22 | 27 |
| 11                | 14      | 18 | 27 | 7  | 4        | 21 | 12 | 29 | 26       | 24 | 24 | 21 | 17         | 18 | 31 | 14 | 29            | 29 | 22 | 26 |
| 12                | 14      | 18 | 27 | 5  | 1        | 21 | 7  | 29 | 26       | 21 | 24 | 19 | 27         | 26 | 28 | 9  | 29            | 29 | 22 | 26 |
| 13                | 12      | 18 | 26 | 2  | 0        | 18 | 6  | 27 | 26       | 21 | 22 | 15 | 26         | 26 | 28 | 4  | 28            | 29 | 22 | 26 |
| 14                | 12      | 17 | 26 | 0  | 19       | 18 | 2  | 27 | 25       | 19 | 22 | 10 | 24         | 25 | 28 | 1  | 28            | 28 | 22 | 26 |
| 15                | 12      | 17 | 25 | 24 | 18       | 17 | 0  | 26 | 23       | 31 | 21 | 7  | 24         | 25 | 24 | 20 | 28            | 28 | 22 | 26 |
| 16                | 11      | 13 | 25 | 24 | 18       | 17 | 23 | 25 | 23       | 31 | 17 | 2  | 24         | 25 | 23 | 20 | 28            | 28 | 22 | 24 |
| 17                | 11      | 8  | 24 | 23 | 18       | 17 | 22 | 25 | 22       | 31 | 17 | 0  | 23         | 23 | 23 | 19 | 28            | 28 | 22 | 24 |
| 18                | 19      | 6  | 23 | 23 | 17       | 17 | 22 | 25 | 22       | 30 | 15 | 30 | 23         | 22 | 23 | 19 | 28            | 28 | 21 | 24 |
| 19                | 19      | 2  | 21 | 23 | 15       | 28 | 22 | 23 | 21       | 28 | 13 | 30 | 21         | 22 | 19 | 18 | 28            | 28 | 21 | 24 |
| 20                | 18      | 0  | 20 | 23 | 15       | 28 | 21 | 23 | 21       | 28 | 8  | 28 | 21         | 21 | 19 | 18 | 25            | 26 | 16 | 18 |
| 21                | 18      | 21 | 20 | 22 | 26       | 28 | 21 | 23 | 19       | 26 | 4  | 27 | 21         | 29 | 19 | 28 | 23            | 22 | 27 | 25 |
| 22                | 18      | 21 | 17 | 22 | 26       | 27 | 21 | 23 | 19       | 25 | 0  | 25 | 20         | 28 | 17 | 27 | 21            | 20 | 24 | 24 |
| 23                | 17      | 21 | 12 | 19 | 25       | 27 | 21 | 23 | 19       | 25 | 24 | 25 | 25         | 28 | 25 | 25 | 19            | 15 | 21 | 20 |
| 24                | 15      | 20 | 8  | 19 | 25       | 25 | 18 | 22 | 18       | 24 | 24 | 24 | 24         | 27 | 24 | 24 | 18            | 8  | 17 | 18 |
| 25                | 15      | 20 | 2  | 18 | 25       | 24 | 18 | 19 | 18       | 24 | 24 | 24 | 23         | 27 | 24 | 23 | 18            | 4  | 15 | 15 |
| 26                | 14      | 19 | 0  | 18 | 24       | 24 | 26 | 18 | 18       | 22 | 23 | 24 | 23         | 24 | 24 | 21 | 16            | 0  | 24 | 11 |
| 27                | 14      | 17 | 26 | 17 | 23       | 23 | 26 | 13 | 29       | 22 | 23 | 24 | 23         | 24 | 22 | 21 | 16            | 22 | 24 | 11 |
| 28                | 20      | 16 | 26 | 17 | 23       | 20 | 25 | 11 | 29       | 18 | 22 | 24 | 22         | 23 | 22 | 20 | 16            | 22 | 22 | 23 |
| 29                | 19      | 16 | 25 | 17 | 23       | 20 | 24 | 8  | 29       | 16 | 22 | 24 | 22         | 23 | 22 | 20 | 15            | 21 | 22 | 22 |
| 30                | 19      | 16 | 25 | 17 | 22       | 18 | 24 | 7  | 27       | 11 | 21 | 21 | 22         | 23 | 22 | 20 | 21            | 21 | 22 | 22 |
| 31                | 19      | 13 | 25 | 16 |          |    |    |    | 27       | 7  | 19 | 20 | 22         | 20 | 20 | 20 |               |    |    |    |

| Demand | May, 09 |   |   |   | June, 09 |   |   |   | July, 09 |   |   |   | August, 09 |   |   |   | September, 09 |   |   |   |
|--------|---------|---|---|---|----------|---|---|---|----------|---|---|---|------------|---|---|---|---------------|---|---|---|
| 1      | 0       | 2 | 1 | 4 | 1        | 4 | 2 | 3 | 2        | 5 | 3 | 4 | 2          | 3 | 0 | 1 | 0             | 0 | 5 | 1 |
| 2      | 1       | 1 | 0 | 1 | 0        | 5 | 1 | 1 | 0        | 2 | 1 | 2 | 0          | 3 | 3 | 2 | 1             | 1 | 6 | 2 |
| 3      | 0       | 4 | 1 | 0 | 0        | 2 | 0 | 4 | 1        | 6 | 0 | 1 | 1          | 2 | 1 | 1 | 0             | 0 | 4 | 1 |
| 4      | 0       | 1 | 1 | 2 | 2        | 0 | 0 | 5 | 0        | 5 | 2 | 0 | 0          | 0 | 1 | 3 | 0             | 0 | 0 | 0 |
| 5      | 2       | 0 | 0 | 1 | 1        | 1 | 1 | 2 | 1        | 3 | 4 | 2 | 0          | 0 | 2 | 0 | 0             | 0 | 1 | 0 |
| 6      | 4       | 2 | 3 | 0 | 0        | 0 | 0 | 3 | 0        | 1 | 0 | 0 | 0          | 3 | 0 | 1 | 0             | 0 | 0 | 0 |
| 7      | 1       | 1 | 2 | 1 | 1        | 2 | 0 | 2 | 0        | 0 | 0 | 0 | 1          | 0 | 1 | 2 | 1             | 0 | 2 | 0 |
| 8      | 0       | 1 | 1 | 0 | 1        | 0 | 2 | 0 | 2        | 0 | 1 | 1 | 0          | 0 | 4 | 0 | 0             | 1 | 2 | 0 |
| 9      | 0       | 0 | 1 | 4 | 4        | 1 | 0 | 1 | 0        | 1 | 0 | 0 | 1          | 0 | 0 | 0 | 0             | 0 | 1 | 0 |
| 10     | 1       | 2 | 0 | 3 | 4        | 0 | 6 | 2 | 1        | 1 | 0 | 1 | 4          | 1 | 0 | 6 | 0             | 0 | 0 | 1 |
| 11     | 0       | 0 | 0 | 2 | 3        | 0 | 5 | 0 | 0        | 3 | 0 | 2 | 0          | 2 | 3 | 5 | 0             | 0 | 0 | 0 |
| 12     | 2       | 0 | 1 | 3 | 3        | 3 | 1 | 2 | 0        | 0 | 2 | 4 | 1          | 0 | 0 | 5 | 1             | 0 | 0 | 0 |
| 13     | 0       | 1 | 0 | 3 | 3        | 0 | 4 | 0 | 1        | 2 | 0 | 5 | 2          | 1 | 0 | 3 | 0             | 1 | 0 | 0 |
| 14     | 0       | 0 | 1 | 2 | 1        | 1 | 3 | 1 | 2        | 0 | 1 | 3 | 0          | 0 | 4 | 2 | 0             | 0 | 0 | 0 |
| 15     | 1       | 4 | 0 | 0 | 0        | 0 | 2 | 1 | 0        | 0 | 4 | 5 | 0          | 0 | 1 | 0 | 0             | 0 | 0 | 2 |
| 16     | 0       | 5 | 1 | 1 | 0        | 0 | 1 | 0 | 1        | 0 | 0 | 3 | 1          | 2 | 0 | 1 | 0             | 0 | 0 | 0 |
| 17     | 2       | 2 | 1 | 0 | 1        | 0 | 0 | 0 | 0        | 1 | 2 | 2 | 0          | 1 | 0 | 0 | 0             | 0 | 1 | 0 |
| 18     | 0       | 4 | 2 | 3 | 2        | 3 | 0 | 2 | 1        | 2 | 2 | 0 | 2          | 0 | 4 | 1 | 0             | 0 | 0 | 0 |
| 19     | 1       | 3 | 1 | 0 | 0        | 0 | 1 | 0 | 0        | 0 | 5 | 2 | 0          | 1 | 0 | 0 | 3             | 2 | 5 | 6 |
| 20     | 0       | 2 | 0 | 1 | 1        | 0 | 0 | 0 | 2        | 2 | 4 | 1 | 0          | 4 | 0 | 0 | 2             | 4 | 4 | 3 |
| 21     | 0       | 0 | 3 | 0 | 0        | 1 | 0 | 1 | 0        | 1 | 6 | 2 | 1          | 1 | 2 | 1 | 2             | 2 | 3 | 1 |
| 22     | 1       | 0 | 5 | 3 | 1        | 0 | 0 | 0 | 0        | 0 | 2 | 0 | 3          | 0 | 2 | 2 | 2             | 5 | 3 | 4 |
| 23     | 2       | 1 | 4 | 0 | 0        | 2 | 3 | 1 | 1        | 1 | 0 | 1 | 1          | 1 | 1 | 1 | 1             | 7 | 4 | 2 |
| 24     | 0       | 0 | 6 | 1 | 0        | 1 | 0 | 3 | 0        | 0 | 0 | 0 | 1          | 0 | 0 | 1 | 0             | 4 | 2 | 3 |
| 25     | 1       | 1 | 4 | 0 | 1        | 0 | 2 | 1 | 0        | 2 | 1 | 0 | 0          | 3 | 0 | 2 | 2             | 5 | 3 | 4 |
| 26     | 0       | 2 | 2 | 1 | 1        | 1 | 0 | 5 | 1        | 0 | 0 | 0 | 0          | 0 | 2 | 0 | 0             | 1 | 0 | 0 |
| 27     | 0       | 1 | 0 | 0 | 0        | 3 | 1 | 2 | 0        | 4 | 1 | 0 | 1          | 1 | 0 | 1 | 0             | 0 | 2 | 3 |
| 28     | 1       | 0 | 1 | 0 | 0        | 0 | 1 | 3 | 0        | 2 | 0 | 0 | 0          | 0 | 0 | 0 | 1             | 1 | 0 | 1 |
| 29     | 0       | 0 | 0 | 0 | 1        | 2 | 0 | 1 | 2        | 5 | 1 | 3 | 0          | 0 | 0 | 0 | 0             | 0 | 0 | 0 |
| 30     | 0       | 3 | 0 | 1 | 1        | 1 | 1 | 4 | 0        | 4 | 2 | 1 | 0          | 3 | 2 | 0 | 0             | 2 | 1 | 2 |
| 31     | 1       | 5 | 1 | 0 |          |   |   |   | 1        | 3 | 1 | 2 | 1          | 1 | 1 | 2 |               |   |   |   |