“Supply chains cannot tolerate even 24 hours of disruption. So if you lose your place in the supply chain because of wild behavior you could lose a lot. It would be like pouring cement down one of your oil wells.”

Thomas Freidman

1.1 AN OVERVIEW OF SUPPLY CHAIN MANAGEMENT

Supply Chain Management (SCM) is a field of growing interest for both companies and researchers. It consists of the management of material, information and financial flows in a logistics distribution network composed of parties like vendors, manufacturers, distributors, retailers and customers. The environment in which companies nowadays manage their SC is highly dynamic. The ever-increasing pressure on engineers/managers to lower production & procurement costs, allocate resources, meet schedules and quality in order to withstand competition has prompted them to look for rigorous methods of decision making. One such exciting hotbed of innovation and a terrific field for researchers is Operational Research (OR). It attempts to provide a substratum to formulate problems and assist in the cognitive process of reaching a decision. In order to aid the process of decision making, modern management is adopting and applying quantitative techniques so as to reinvigorate the performance of the organization. This is due to the fact that an intelligent application of the appropriate techniques can reduce an otherwise unwieldy and complex problem to one of manageable dimensions. One such speedily elevating technique which enhances performance both qualitatively and quantitatively is Optimization Techniques. Optimization Techniques is the art and science of allocating scarce resources to the best possible effect. The art lies in the ability to depict the concepts efficient and scarce in a well-defined Mathematical Model of a given situation. The science consists in the derivation of computational methods for solving such models. These are called into play every day in questions of planning, resource allocation, scheduling, decision making etc. Thus, optimization, which is a powerful tool of OR, is regarded as a tool of conceptualization and analysis. This thesis is devoted to the development of optimization tools that enable companies to detect, and subsequently take advantage of, opportunities that may exist for improving the efficiency of their SC networks in such a dynamic environment.
In the last few years, many companies have been able to substantially increase revenue or decrease costs through effective SCM. So SCM is perhaps the single most important factor determining the success of the firm. Indeed, companies compete on cost and service levels, the two key elements in the SCM.

In a typical SC, raw materials are procured and items are produced at one or more factories, shipped to warehouses for intermediate storage, and then shipped to retailers or customers (Figure 1.1). Consequently, to reduce cost and improve service levels, effective SC strategies must take into account the interactions at various levels in the SC. The SC consists of suppliers, manufacturing centers, warehouses, distribution centers and retail outlets, as well as raw materials, work-in-process inventory and finished products and other functions involved in receiving and filling a customer request that flow between the facilities.

![Supply Chain Flow](image)

**Figure 1.1: Supply Chain Flow**

These functions include, but are not limited to, new product development marketing, operations, distribution, finance and customer service. A SC is dynamic and involves the constant flow of information, product, and funds between different stages. The customer is an integral part of the SC. In fact, the primary purpose of any SC is to satisfy customer needs and in the process generate profit for itself. The term SC conjures up images of product or supply moving from suppliers to manufacturers to
distributors to retailers to customers along a chain. This is certainly a part of SC, but it is also important to visualize information, funds, and product flows along both directions of the chain.

1.1.1 Objectives of Supply Chain Management

The standard statement of the objectives of the supply function is that it should obtain the right materials (meeting quality requirements), in the right quantity, for delivery at the right time and right place, from the right source (a supplier who is reliable and will meet its commitments in a timely fashion), with the right service (both before and after the sale), and at the right price in the short and long term. The supply decision maker might be likened to a juggler, attempting to keep several balls in the air at the same time, for he or she must achieve these seven rights simultaneously. It is not acceptable to buy at the lowest price if the goods delivered are unsatisfactory from a quality/performance standpoint, or if they arrive two weeks behind schedule. On the other hand, the right price may be higher than normal if the item in question is an emergency requirement where adherence to normal lead time would result in a higher total cost of ownership. The right price is one aspect of lowest total cost of ownership. The supply decision maker attempts to balance the often-conflicting objectives and makes trade-offs to obtain the optimum mix of these seven rights. Obtaining this balance with an eye to both the short term and the long term requires supply managers to have both a tactical and strategic perspective [Bowersox and Closs, (2000)].

A more encompassing statement of the overall goals of supply would include the following seven goals:

a. Improve the organization's competitive position. As a strategic player, the activities of supply management must be focused on contributing to overall organizational strategy, goals and objectives. Supply managers must identify and exploit opportunities in the SC to contribute to revenue enhancement, asset management and cost reduction. Supply can secure the lowest total cost source of supply, provide access to new technologies and design flexible delivery arrangements, fast response times, access to high-quality products or services, and product design and engineering assistance.
b. **Provide an uninterrupted flow of materials, supplies, and services required to operate the organization.** Stockouts or late deliveries of materials, components, and services can be extremely costly in terms of lost production, lower revenues and profits and diminished customer goodwill. For example, (1) an automobile producer cannot complete the car without purchased tires, (2) an airline cannot keep its planes flying on schedule without purchased fuel, (3) a hospital cannot perform surgery without purchased surgical tools, and (4) an office cannot be used without purchased maintenance services.

c. **Keep inventory investment and loss at a minimum.** One way to ensure an uninterrupted material flow is to hold large inventories. But inventory assets require use of capital that cannot be invested elsewhere and the cost of carrying inventory may be 20 to 50 percent of its value per year. For example, if purchasing can support operations with an inventory investment of $10 million instead of $20 million, at an annual inventory carrying cost of 30 percent, the $10 million reduction in inventory represents a savings of $30 million in addition to freeing $10 million in working capital.

d. **Maintain and improve quality.** A certain quality level is required for each material or service input; otherwise the end product or service will not meet expectations or will result in higher-than-acceptable costs. The cost to correct a substandard quality input could be huge. Continuous improvement in supplier quality is directly linked to an organization's ability to compete effectively on a worldwide basis.

e. **Find or develop best-in-class supplier.** The success of supply depends on its ability to link supply base decisions to organization strategy and its skill in locating or develop suppliers, analyzing supplier capabilities, selecting the appropriate supplier and then working with that supplier to obtain continuous improvements. Only if the final selection results in suppliers who are both responsive and responsible only then the firm will obtain the services it needs.

f. **Purchase required items and services at lowest total cost of ownership.** Purchased goods and services in the typical organization represent the largest share of that organization's total costs. Consequently, the profit-leverage effect
can be significant. Price is the most convenient method to compare competing proposals from suppliers. However, supplier's responsibility is to obtain the needed goods and services at the lowest total cost of ownership, which necessitates consideration of other factors-such as quality levels, after-sales service, warranty costs, inventory and spare parts requirements, downtime and so forth-that in the long term might have a greater cost impact on the organization than the original purchase price.

g. **Accomplish supply objectives at the lowest possible operating costs.** It takes resources to operate supply: salaries, communications expense, supplies, travel costs, computer costs, and accompanying overhead. The objectives of supply should be achieved as efficiently and economically as possible. Process inefficiencies represent waste and lead to excessive operating costs and unnecessarily high total cost of ownership. Supply managers should be continually alert to improvements possible in purchasing and supply processes, methods, procedures, and techniques. For example, opportunities to reduce transaction costs include e-procurement systems that automate the process from requisition to payment and purchasing cards and e-catalogs for small-value purchases. Companies with efficient supply processes can create competitive advantage through reduced costs, improved flexibility, faster time to market, and greater compliance, while allowing supply personnel to concentrate on value-added activities.

The objectives of supply must ultimately contribute to the attainment of short- and long-term organizational strategy, goals and objectives. The process and function can be organized in a number of different ways to maximize supply's contribution effectively and efficiently.

### 1.2 SUPPLY CHAIN DECISIONS

Several models have been proposed for understanding the activities required to manage material movements across organizational and functional boundaries. SC activities can be grouped into strategic, tactical, and operational levels (Figure 1.2). Issues which span a large spectrum of firm’s activities are:
The **strategic level** deals with the decisions that have a long lasting effect on firm. This includes decisions regarding the number, location, capacity of warehouses and manufacturing plants, and the flow of material through the network. As the terms implies, strategic decisions are made typically over a longer time horizon. These are closely linked to the corporate strategy and guide SC policies from a design perspective. The decisions can be of the following types.

a. Strategic network optimization, including the number, location, and size of warehousing, distribution centers and facilities.

b. Strategic partnerships with suppliers, distributors and customers, creating communication channels for critical information and operational improvements such as cross docking, direct shipping, and third-party logistics.

c. Product life cycle management, so that new and existing products can be optimally integrated into the SC and capacity management activities.

d. Information technology chain operations.

e. Where-to-make and make-buy decisions.

f. Aligning overall organizational strategy with supply strategy.
The **tactical level** includes decisions that are typically updated anywhere between once every quarter and once every year. These include purchasing and production decisions, inventory policies and transportation strategies, including the frequency with which customers are visited. The decisions can be of the following types.

a. Sourcing contracts and other purchasing decisions.

b. Production decisions, including contracting, scheduling and planning process definition.

c. Inventory decisions, including quantity, location and quality of inventory.

d. Transportation strategy, including frequency, routes and contracting.

e. Benchmarking of all operations against competitors and implementation of best practices throughout the enterprise.

f. Focus on customer demand and habits.

The **operational planning** refers to day-to-day decisions such as scheduling, lead time quotations, routing and truck loading. On the other hand, operational decisions are short term, and focus on activities over a day-to-day basis. The effort in these types of decisions is to effectively and efficiently manage the product flow in the "strategically" planned SC. SCM includes activities from purchasing, order handling, production and distribution. All these areas include other activities. All these activities have to be considered when setting up a SC. The decisions can be of the following types.

a. Daily production and distribution planning, including all nodes in the SC.

b. Production scheduling for each manufacturing facility in the SC (minute by minute).

c. Demand planning and forecasting, coordinating the demand forecast of all customers and sharing the forecast with all suppliers.

d. Sourcing planning, including current inventory and forecast demand, in collaboration with all suppliers.

e. Inbound operations, including transportation from suppliers and receiving inventory.
f. Production operations, including the consumption of materials and flow of finished goods.

g. Outbound operations, including all fulfillment activities, warehousing and transportation to customers.

h. Order promising, accounting for all constraints in the SC, including all suppliers, manufacturing facilities, distribution centers and other customers.

i. From production level to supply level accounting all transit damage cases & arrange to settlement at customer level by maintaining company loss through insurance company.

j. Managing non-moving, short-dated inventory and avoiding more products to go short-dated.

There are four major decision areas in SCM: a) location, b) production, c) inventory, and d) transportation (distribution) and there are strategic, tactical and operational elements in each of these decision areas.

### 1.2.1 Location Decisions

Location decisions are primarily strategic; they also have implications on an operational level. The geographic placement of production facilities, stocking points and sourcing points is the natural first step in creating a SC. The location of facilities involves a commitment of resources to a long-term plan. Once the size, number and location of these are determined, so are the possible paths by which the product flows through to the final customer. These decisions are of great significance to a firm since they represent the basic strategy for accessing customer markets and will have a considerable impact on revenue, cost and level of service. These decisions should be determined by an optimization routine that considers production costs, taxes, duties and duty drawback, tariffs, local content, distribution costs, production limitations, etc. [Arntzen et al. (1995)].

### 1.2.2 Production Decisions

The strategic decisions include what products to produce and which plants to produce them in, allocation of suppliers to plants, plants to Distribution Center’s (DC’s) and
DC's to customer markets. As before, these decisions have a big impact on the
revenues, costs, and customer service levels of the firm. These decisions assume the
existence of the facilities, but determine the exact path(s) through which a product
flows to and from these facilities. Another critical issue is the capacity of the
manufacturing facilities-and this largely depends on the degree of vertical integration
within the firm. Operational decisions focus on detailed production scheduling. These
decisions include the construction of the master production schedules, scheduling
production on machines and equipment maintenance. Other considerations include
workload balancing and quality control measures at a production facility.

1.2.3 Inventory Decisions

These refer to means by which inventories are managed. Inventories exist at every stage
of the SC as either raw material, semi-finished or finished goods. They can also be in-
process between locations. Their primary purpose is to buffer against any uncertainty that
might exist in the SC. Since holding of inventories can cost anywhere between 20 to 40
percent of their value, their efficient management is critical in SC operations. It is
strategic in the sense that top management sets goals. However, most researchers have
approached the management of inventory from an operational perspective. These include
deployment strategies (push versus pull), control policies -- the determination of the
optimal levels of order quantities and reorder points and setting safety stock levels, at
each stocking location. These levels are critical, since they are primary determinants
of customer service levels. Some basic models and factors affecting these decisions
are discussed further.

1.2.4 Transportation Decisions

The mode choice aspects of these decisions are the more strategic ones. These are
closely linked to the inventory decisions, since the best choice of mode is often found
by trading-off the cost of using the particular mode of transport with the indirect cost
of inventory associated with that mode. While air shipments may be fast, reliable and
warrant lesser safety stocks, they are expensive. Meanwhile shipping by sea or rail
may be much cheaper, but they necessitate holding relatively large amounts of
inventory to buffer against the inherent uncertainty associated with them. Therefore customer service levels and geographic location play vital roles in such decisions. Since transportation is more than 30 percent of the logistics costs, operating efficiently makes good economic sense. Shipment sizes (consolidated bulk shipments versus Lot-for-Lot), routing and scheduling of equipment are key in effective management of the firm's transport strategy. Some basic models and factors affecting these decisions are discussed further.

Clearly each of the above levels of decisions (strategic, operational and tactical) requires a different perspective. The strategic decisions are, for the most part, global or "all encompassing" in that they try to integrate various aspects of the SC. Consequently, the models that describe these decisions are huge and require a considerable amount of data. Often due to the enormity of data requirements and the broad scope of decisions, these models provide approximate solutions to the decisions they describe. The operational decisions, meanwhile, address the day to day operation of the SC. Therefore the models that describe them are often very specific in nature. Due to their narrow perspective, these models often consider great detail and provide very good solutions to the operational decisions.

### 1.2.5 Key Issues & Some Trade-Offs Associated With Different Decisions

1. **Distribution Network Configuration** – consider several plants producing products to serve a set of geographically dispersed retailers. The current set of warehouses is deemed inappropriate because of changing demand patterns which requires a change in plant production levels, a selection of new suppliers and a new flow pattern of goods throughout the distribution network.

2. **Supply Contracts** – relationships between suppliers and buyers are established by means of supply contracts that specify pricing and volume discounts, delivery lead times, quality, returns, and so forth.

3. **Distribution Strategies** – a distribution strategy in which the stores are supplied by central warehouses that act as coordinator of the supply process and transshipment points for incoming orders from outside vendors is called cross dock strategy.
4. **Supply Chain Integration and Strategic Partnering** - integrated and globally optimal SC have a huge impact on the company’s performance and market share. In today’s competitive market, most companies have no choice, they are forced to integrate their SC and engage in strategic partnering. This pressure stems from both their customers and their SC partners.

5. **Outsourcing and Procurement Strategies** – SC strategy not only involves coordinating the different activities in the SC, but also deciding what to make internally and what to buy from outside sources.

6. **Product Design** – effective design plays several critical roles in the SC as several product designs may increase holding or transportation costs relative to other designs, while others may facilitate a shorter manufacturing lead time.

7. **Information technology and Decision-Support System** – information technology is a critical enabler of effective SCM. Indeed, much of the current interest in the SCM is motivated by the opportunities that appeared due to the abundance of data and the savings that can be achieved by sophisticated analysis of these data. The primary issue in the SC is not whether data can be received, but what data should be transferred; i.e. which data are significant for SCM and which data can be safely ignored.

8. **Customer Value** – it’s the measure of a company’s contribution to its customer, based on the entire range of products, services, and intangibles that constitute the company’s offerings.

These issues and trade-offs can be solved by usage of dynamic approaches given by OR, described in further sections.

### 1.3 OPERATIONAL RESEARCH IN SUPPLY CHAIN MANAGEMENT

Operational Research (OR) had its origin in World War II, which witnessed the most realistic and aggressive form of competition. During this time, new approaches to solve optimization problems strategically and tactfully were discovered. Exemplary contributions were made by famous scientists during that era which gave a structural form to OR. Today, OR has become a vibrant and dynamic subject with rich
theoretical bases and numerous important applications in fields ranging as wide as communication, software, business, industries, finance, medicine, manufacturing, product design, SCM, transportation, and sports to name a few. It attempts to provide a systematic and rational approach to the fundamental problems involved in the control of systems by making functional decisions. This dominant and indispensable decision making tool assists in achieving the best results in light of all the valuable information. The foundation of OR is mathematical modeling.

Optimization techniques are then employed on these models to obtain the best course of action for the process being studied. Optimization methods, coupled with modern tools of computer-aided design, are also being used to enhance the creative process of conceptual and detailed design of engineering systems, including manufacturing units, logistics, research and development and even SCM. To a large extent conceptually, OR and related mathematical modeling, and optimization procedures are used to increase effectiveness in a competitive environment. The optimization models developed for engineering and business professionals in reducing the cost in SC, allow them to choose the best course of action and experiment with the various possible alternative decisions. Mathematical modeling and optimization for the competent planning and control of the SC process is the area of prime interest in the field of OR. Research in this field has grown enormously. Various new techniques and algorithms have been proposed in the field of mathematics, OR and management by many scholars in their literature over the years. Figure 1.3 illustrates the need of optimization techniques which steers the course of planning, resource allocation, scheduling and decision making.

![Figure 1.3: Need of Optimization Techniques](image-url)
1.3.1 Operational Research in Supply Chain: A Review

The mission of OR is to support real-world decision making using mathematical and computer modeling, [Luss and Rosenwein (1997)]. SCM is one of the areas where OR has proved to be a powerful tool, [Geunes and Chang (2009)] and [Tayur et al. (1999)]. Bramel and Simchi-Levi (1997) claim that, in logistics management practice, the tendency to use decision rules that were adequate in the past, or that seem to be intuitively good, is still often observed. However, it proved to be worth while using scientific approaches to certificate a good performance of the SC or to detect opportunities for improving it. Many times this leads to a more effective performance of the SC while maintaining or even improving the customer service level. There are many examples of different scientific approaches used in the development of decision support systems [Nunen and Benders (1981)], [Benders et al. (1986)], and [Hagdorn (1996)], or the development of new optimization models representing the situation at hand as closely as possible [Geoffrion and Graves (1974)], [Gelders et al. (1987)], [Fleischmann (1993)], [Chan, Muriel and Simchi-Levi (1998)], [Klose and Stahly (1998)], and [Tushaus and Wittmann (1998)]. Geoffrion and Powers (1995) summarize some of the main reasons for the increasing role of optimization techniques in the design of distribution systems. The most crucial one is the development of the capabilities of computers that allow for the investigation of richer and more realistic models that could be analyzed before. In these extended models, additional important issues, e.g. scenario analysis, can be included. This development in computer technology is accompanied by new advances in algorithms, [Nemhauser (1994)]. The vast literature devoted to quantitative methods in SCM also suggests the importance of OR in this field. Bramel and Simchi-Levi (1997) have shown the power of probabilistic analysis when defining heuristic procedures for distribution models. Geunes and Chang (2009) give a survey of models in OR emphasizing the design of the SC and the coordination of decisions. Tayur et al. (1999) have edited a book on quantitative models in SCM. In a more practical setting, Gelders et al. (1987) use a plant location model for the reorganization of the logistics distribution networks of two small breweries into a single bigger one. Shapiro et al. (1993) develop a Decision Support System based on Mathematical Programming tools to consolidate the value
chains of two companies after the acquisition of these conditions by the first one. Arntzen et al. (1995) present a multi-echelon multi-period model which was used in their organization of Digital Equipment Corporation. Hagdornv (1996) presents some examples of companies where new structures have been implemented recently. Koksalan and Sural (1999) use a multi-period Mixed Integer Problem for the opening of two new malt plants for Efes Beverage. Myers (1992) presents an optimization model to forecast the demand that a company producing plastic closures can accommodate when these closures suffer from marketing perishability. From an environmental point of view, decreasing the freight traffic is highly desirable. Kraus (1998) claims that most of the environmental parameters for evaluating transportation in distribution networks are proportional to the total distance traveled, thus a lot of effort is put in to developing systems that decrease that distance. Most of the authors discussed about SC in relation with optimization techniques, a powerful decision making tool.

1.4. OPTIMIZATION PROBLEMS

Generally, optimization problems seek a solution where decisions need to be made in a constrained or limited resource environment. Most SC optimization problems require matching demand and supply when one, the other, or both may be limited. By and large, the most important limited resource is the time needed to procure, make, or deliver something. Since the rate of procurement, production, distribution and transportation resources is limited, demand cannot be instantaneously satisfied. It always takes some amount of time to satisfy demand, and this may not be quick enough unless supply is developed well in advance of demand. In addition to time, other resources, such as warehouse storage space or a truck's capacity, may be constrained in meeting demand.

**Decision Variables** are within the planner's span of control:

- When and how much of a raw material to order from a supplier
- When to manufacture an order
- When and how much of the product to ship to a customer or distribution center
Constraints are limitations placed upon the supply plan:

- A supplier's capacity to produce raw materials or components
- A production line that can only run for a specified number of hours per day and a worker that must only work so much overtime
- A customer's or distribution center's capacity to handle and process receipts

Constraints in an optimization problem are either hard or soft. Hard constraints, such as the number of working hours in a shift or the maximum capacity of a truck, must be adhered to or satisfied. Soft constraints can be relaxed or violated. Examples of soft constraints include customer due dates or warehouse space limitations. Customer due dates can be changed or a product may be squeezed into a warehouse temporarily, making constraints less stringent. Most optimization problem formulations designate cost penalties if a soft constraint is not met. The penalties allow constraints to be weighted by importance. For example, missing a customer due date is a more important concern than cluttering a warehouse aisle.

Objectives are the goals of the firm that maximize, minimize, or satisfy something, such as the following:

- Maximizing profits or margins
- Minimizing SC costs or cycle times
- Maximizing customer service
- Minimizing lateness
- Maximizing production throughput
- Satisfying all customer demand

Models describe the relationships among decisions, constraints and objectives. These are often expressed in the form of mathematical equations. This is probably the most important but least understood part of an optimization problem. Generally, the model must represent the "real world" to the degree needed to capture the essence of the problem. It must represent the important aspects of the SC in order to provide a useful solution. For example, strategic planning typically uses aggregate models, which do not include every factor. On the other hand, operational planning uses models that include almost all factors and require detailed data.
Once an optimization problem is formulated, a *solver* determines the best course of action. A solver comprises a set of logical steps or algorithms embodied in a computer program to search for a solution that achieves the objective. A solver can develop three types of solutions:

- **Feasible Solution**—satisfies all the constraints of the problem.
- **Optimum Solution**—the best feasible solution that achieves the objective of the optimization problem. Although some problems may yield more than one feasible solution, there is usually only one optimum.
- **Optimized Solution**—a solution that partially achieves the objective of the optimization problem. It is not the optimum or best solution, but it is a satisfying or reasonable one. This is usually one of the best feasible solutions. However, for optimization problems that have no feasible solutions, it may be one of the best infeasible solutions. For example, in a resource-constrained environment, it may be a solution that is infeasible because it does not meet all customer due dates, but it may minimize operating costs.

### 1.5 SUPPLY CHAIN OPTIMIZATION

Recently, in a fashion similar to the Artificial Intelligence efforts, there has been a trend to embed sophisticated optimization logic into Advanced Planning and Scheduling (APS) suites to improve decisions of SC planners. If used successfully, this type of optimization promises to drastically improve a company’s SC performance in a variety of areas:

- Reduced SC costs
- Improved product margins
- Lower inventories
- Increased manufacturing throughput
- Better return on assets

This potential for improvement is generating a great deal of interest in SC optimization. Many established and startup APS vendors are now using the concept as
a selling point, and in some cases, as a key marketing differentiator. While optimization methods have been around since post World War II--with the advent of OR and management sciences--there has been only a marginal interest in applying these concepts to SC planning. The growing optimization technology market and reasons for its growth

Today's market dynamics have made SCs extremely complex and planning more difficult. The following true story is a case in point [U4]:

*ABC Inc., a small, 100-year-old agricultural seed company called in a consultant to work on a production scheduling problem. The consultant talked to upper management and found that over the last couple of years the company was having difficulty meeting increasingly diverse customer needs. The president, who came from a Fortune 500 company, seemed to understand the problem best. One night, he noted his production planning people were working later than usual and he asked them why. They said that they had been working to develop a plan that would meet marketing's forecasts, but they were not able to do it, despite working on it for a couple of weeks! Over the last few years, the business had become very competitive and the company's product line had expanded to several hundred items, making planning much more difficult. The president explained that, while these planners had over 20 years of experience, the complexity of the environment had exceeded their ability to do the production plan on paper and spreadsheets using the guidelines and rules-of-thumb that they had developed over the years. The president stated he wanted the consultant to develop software to help them schedule better. He was familiar with this type of software from his experience at the Fortune 500 company. The consultant said, "Of course, you will want the software to give the planners the optimal lowest cost solution." The president stated: "This would be extremely desirable, but just make sure it gives them a production plan that meets our marketing forecasts, as well as our production and distribution needs. Right now, it is of paramount importance that we generate realistic plans that satisfy our customer demand."

The situation at ABC Inc., described above, has been happening for many years in all sizes and types of companies throughout the manufacturing industry. Customer demand and competition have made SC planning and scheduling more challenging
and complex. A number of major trends have contributed to this increasing complexity:

- Customer demand for shorter cycle times and specialized packaging/delivery requirements
- Mass customization of products
- Product line and stock keeping unit (SKU) proliferation
- Globalization of operations--including sourcing, production, sales and marketing
- Greater outsourcing of manufacturing operations
- Increased use of third party logistics (3PL) providers
- Implementation of co-managed inventory programs with both suppliers and customers, such as vendor managed inventory (VMI) and continuous replenishment programs (CRP)
- Implementation of agile manufacturing initiatives
- Implementation of SC integration concepts
- Company mergers, acquisitions, and consolidations

These trends are contributing to an explosion in the number of entities that have to be planned for, driven by increases in the number of the following elements:

- Items
- Production and distribution facilities
- Functions
- Customers and suppliers

For many years manufacturers have been moving toward improved use of technology to support complex, diverse planning processes. Some, such as ABC Inc., are doing it largely to maintain control of their operations in order to meet customer demand. Having already achieved control, many manufacturers are using APS technology to increase the productivity of planning processes and to lower SC costs.
Generally, companies are looking for planning solutions that consider major supply constraints, which leads them to constraint-based optimization. SC planning optimization techniques and solutions attempt to accomplish the following tasks:

- Determine a feasible plan that meets all demand needs and supply limitations
- Optimize the plan in relation to corporate goals such as low cost and profitability
- While the term optimization is confusing to buyers, the APS market is getting a lot of attention. This is primarily driven by the increasing complexity of manufacturers SCs. This complexity is caused both by the trend toward globalization and the myriad products, materials, facilities, trading partners, and trading relationships that need to be planned. In many companies, planners are becoming overwhelmed by the complexity, and they need better computer support in decision-making.
- The ability to model a manufacturer's environment adequately is a critical success factor in being able to use computer-generated optimized decisions. The availability of data to input into one's SC models is closely related to this factor. Thus, modeling capabilities and data requirements are the key factors to consider in implementing optimization solutions.
- One of the most confusing aspects of the optimization market is the variety of solver methods marketed with names like Mathematical Programming, Heuristics, Theory of Constraints, Simulated Annealing, and Genetic Algorithm. Generally, vendors employ solvers depending upon the structure of the optimization model. By and large, vendors are diligent (some even fervent!) in using appropriate methods within their solvers--whether the methods are proprietary, purchased from another vendor, or based on known methods. This makes solver type a secondary consideration in choosing among different optimization-based applications.
- Vendors design their optimization applications in various ways. This makes comparing them difficult and requires taking a hard look at each vendor's solution.
1.5.1 Challenges in Supply Chain Management

It’s challenging to design and operate a SC so that total system wide costs are minimized and system wide service levels are maintained. Indeed it is frequently difficult to operate a single facility so that costs are minimized and service level is maintained. The difficulty increases exponentially when an entire system is being considered. The process of finding the best system wide strategy is known as global optimization. A variety of factors make this a challenging problem [Simchi and Kaminsky (2000)]:

The first and the big challenge in SC is SC itself as it is complex network of facilities dispersed over a large geography, and in many cases, all over the globe. These network of facilities frequently have different, conflicting objectives. For instance, suppliers typically want manufacturers to commit themselves to purchasing large quantities in stable volumes with flexible delivery dates. Unfortunately, although most manufacturers would like to implement long production runs, they need to be flexible to their customers’ needs and changing demands. Thus, the suppliers’ goals are in direct conflict with the manufacturers’ desire for flexibility. Indeed, since production decisions are typically made without precise information about customer demand, the ability of manufacturers to match supply and demand depends largely on their ability to change supply volume as information about demand arrives. Similarly, the manufacturer’s objective of making large production batches typically conflicts with the objectives of both warehouses and distribution centers to reduce inventory. To make matters worse, this latter objective of reducing inventory levels typically implies an increase in transportation costs.

The other complexity is that, the SC is the dynamic system that evolves over time. Indeed, not only do customer demand and supplier capabilities change over time, but SC relationships also evolve over time. For example, as customers’ power increases, there is increased pressure placed on manufacturers and suppliers to produce an enormous variety of high-quality products and, ultimately, to produce customized products.

The next difficulty is System Variations. System variations over time are also an important consideration even when demand is known precisely (e.g., because of contractual
agreements), the planning process needs to account for demand and cost parameters varying over time due to the impact of seasonal fluctuations, trends, advertising and promotions, competitor’s pricing strategies and so forth. These time-varying demand and cost parameters make it difficult to determine the most effective SC strategy, the one that minimizes system wide costs and conforms to customer requirements.

Of course, global optimization only implies that it is not only important to optimize across SC facilities, but also across processes associated with the development and SCs. That is, it is important to identify processes and strategies that optimize, or, alternatively, synchronize, both chains simultaneously. Global optimization is made even more difficult because SCs need to be designed for and operated in, uncertain environments, thus creating sometimes enormous risks to the organization. Uncertainty is inherent in every SC; customer demand can never be forecast exactly, travel time will never be certain, machines and vehicles will break down. SC needs to be designed to eliminate as much uncertainty as possible and to deal effectively with the uncertainty that remains. A variety of factors contribute to this:

Matching supply and demand is a major challenge. Boeing Aircraft announced a write-down of $2.6 billion in October 1997 due to raw material shortages, internal and supplier parts shortages and productivity inefficiencies.

Inventory can enter our system in number of ways and it’s a constant challenge to keep it under control”. Intel, the world’s largest chip maker, reported in a magazine a 38 percent decline in quarterly profit in the face of stiff competition from Advanced Micro Devices and a general slowdown in the personal computer market that caused inventories to swell. Obviously, this difficulty stems from the fact that months before demand is realized, manufacturers have to commit themselves to specific production levels. These advance commitments imply huge financial and supply risks.

Inventory and back-orders level fluctuate considerably across the SC, even when customer demand for specific products does not vary greatly. To illustrate this issue, consider Figure 1.4, which suggests that in a typical SC, distributor orders to the factory fluctuate far more than the underlying retailer demand.
Figure 1.4: Order Variations in Supply Chain

Forecasting doesn’t solve the problem. Indeed, we will argue that the first principle of forecasting is that “forecasts are always wrong.” Thus, it is impossible to predict the precise demand for a specific item, even with the most advanced forecasting techniques.

Demand is not only source of uncertainty. Indeed delivery lead times, manufacturing yields, transportation times, and component availability can also have significant SC impact.

So the ability to replace traditional SC strategies, in which each facility or party in the chain makes decisions with little regard to their impact on other SC partners, by those that yield global optimized SC. And the ability to effectively manage uncertainty is a major issue because the level of demand uncertainty has increased in last few years. Indeed in high-tech industries, product life cycles are becoming shorter and shorter.

In order to quantify these uncertainties defining the problem under fuzzy environment of OR techniques offers the opportunity to model subjective imagination of the
decision maker as precisely as a decision maker will be able to describe it. Optimization under fuzzy environment is gaining even more importance in the era of globalization due to some additional sources i.e. stiff competition, shorter life cycles of products, contributing to bringing uncertainties in the problem definitions. It is a flexible approach that permits a more adequate solution of real problems in the presence of vague information. The fuzzy set concept and fuzzy optimization techniques can be used efficiently in such situations to defuzzify the fuzzy parameters, constraints and objectives and formulating an equivalent crisp problem which can further be solved using the mathematical programming techniques. Even though the fuzzy optimization procedure is highly subjective to the problem solver due to the subjectivity of the defuzzification techniques; it is preferred as it provides flexibility in terms of the alternative courses of action to the decision maker. In the current work, we have discussed in detail and solved procurement and distribution decision problems, formulated under fuzzy environment, at least one of the sections in each chapter and a literature survey is done on fuzzy systems modeling in section 1.6.

1.5.2 Supply Chain Optimization: Tools & Techniques

Models and data are two very important elements of SC optimization. A plan's usefulness greatly depends on the quality of both. If a planning process is based on a model that inadequately represents reality or if the data used in a model is wrong, the solutions developed by the optimization will not be meaningful or executable. The two elements go hand-in-hand for the following reasons:

- Data is always needed to populate a model.
- A model should not be built needing data that is not available.

Another important element of an optimization process is the solver, which solves for an optimized solution. A SC planning optimization process requires good quality models. For good optimization, the level of detail in the model must be appropriate for the planning level. While models and data are extremely important to the usefulness of a plan developed using optimization, realistic, executable plans can sometimes be developed without detailed models and data. A common guideline in SC planning optimization is that detailed models are not needed for strategic planning.
but are needed for operational and tactical planning. For strategic and higher levels of
tactical planning, a model could be based on aggregate data such as product groupings
or regional demand. It is important for an operational model to be based on detailed
data such as SKUs and customer orders.

In addition to models and data, solvers are important since they generate the
optimized solutions. Many of these methods were developed to solve problems with a
specific model or mathematical structure, while others were developed to improve the
computational speed of the solver. This led to esoteric names for these solvers and
added to their "rocket-science" positioning. Optimization solvers use and are named
for the different methods or algorithms deployed to find solutions. These methods can
be grouped into four categories:

- Heuristics (including scheduling methods like the Theory of Constraints or
  Simulated Annealing)
- Genetic algorithms
- Exhaustive enumeration
- Mathematical programming (largely linear and mixed integer non-linear
  programming)

Generally, mathematical programming methods are used in solvers for strategic and
higher levels of tactical planning. These methods generally work for solving linear
and some non linear integer-based models, commonly used in strategic levels of
planning. Tactical and operational models are usually not linear and are much too
complex to solve using mathematical programming methods. For this reason, heuristic
methods are generally used in tactical and operational planning level solvers.

Genetic algorithms are used primarily in operational planning to consider a large
number of possible solutions. The Theory of Constraints, a heuristic method based on
work by Eli Goldratt, is another solver method commonly used in operational
planning. Vendors that use solvers based on the Theory of Constraints include i2
Technologies, STG, Thru-Put Technologies.

While not a formal optimization technique, exhaustive enumeration is predicated on
using the computer to find a solution by looking at all possible alternative plans. This
method proves useful in simple SC situations. Otherwise, this method is computationally intensive and slow to generate a solution. Distinction Software (Atlanta, GA), uses this optimization method for its manufacturing planning solution. Since the company focuses on mid-tier and smaller manufacturers, the exhaustive enumeration approach is feasible, the details of all the above methods are as follows.

1.5.2.1 Heuristics

Heuristic methods are predicated on trying to improve a known feasible solution following prescribed steps. Heuristics do not guarantee that an optimum solution can be found, nor do they determine how much better an optimum solution might be. As an illustration, a simple heuristic for maximizing an objective might follow a three-step approach:

- Start all decision variables at 0 value.
- Continue increasing decision variables one at a time as long as the objective continues to increase.
- Stop when increasing all decision variables no longer increases the objective.

While this heuristic method might not lead to the optimum, solutions will usually get better or stay the same. Simply put, heuristics are based on the logic a reasonable person might follow in looking for an optimum. Some scheduling optimization solutions use heuristic logic based on the Theory of Constraints (TOC) espoused by Eli Goldratt. These methods focus on critically constrained resources or "bottlenecks" to develop a schedule. The TOC approach revolves around a drum, buffer and rope concept. First, TOC uses the critically constrained resources to develop a master plan or drum that the plant or system beats to or to which the pace is set. Buffers, such as work-in-process inventories and surplus time in the schedule, are put in place to ensure maximum utilization of the critically constrained resources that ensure they do not sit idle. Lastly, all non-critically constrained resources are "tied" together according to the drum, creating so-called ropes that pull work through the system. In addition to TOC, there are many types of heuristic methods that are proprietary knowledge are of the vendors. Some of these are based on known, published approaches such as Simulated Annealing and Repair-Based Scheduling methods.
1.5.2.2 Genetic Algorithms

Genetic algorithms are predicated on a biological selective breeding concept of survival of the fittest. The methods attempt to find an optimized solution from a large set of possible solutions by comparing them and selecting the best ones of the group. The ones that survive this test are then mutated or crossbred to establish another set of solutions. This search method continues testing from generation-to-generation for some duration of time, thereby developing a reasonably optimized solution. These methods work well when a baseline schedule or plan exists. For example, sequencing a number of orders through a single assembly-line operation to maximize on-time delivery or to minimize changeover is an optimization task where genetic algorithms could be used.

1.5.2.3 Exhaustive Enumeration

The exhaustive enumeration method evaluates all possible combinations of decisions to find the best combination but it is not considered a formal optimization technique. This method is used when there are relatively few decision-variable combinations to consider. For example, a job shop with 1 machine and 10 orders to sequence would generate 3.6 million potential combinations for evaluation. While this is a lot for a human to handle, it is an easy task for a computer.

1.5.2.4 Mathematical Programming

Mathematical programming methods are used for problems that can be modeled with equations that describe the constraints and objectives. Mathematicians have proved that if a problem can be described using certain sets of equations, then an optimum solution can be computed following a prescribed algorithm or technique. This is in contrast to other methods that search for an optimum but offer no guarantee that it can be found. The most commonly used mathematical programming technique is linear programming (LP). This method works only if all the constraints and a single objective can be expressed as linear equations (i.e., a linear equation looks like this: \( \sum X_{jk} - D_jZ_{kj} = 0 \)). If this holds, the optimum solution that either maximizes or minimizes the single objective can be generated. LP assumes that the decision
variables can be expressed as regular, continuous numbers. If some decisions can only be expressed as an integer or whole number, LP does not work. For example, if the decision is to incur a production changeover or setup, this can only be expressed as a "yes" or "no" or mathematically as a "0" or a "1."

To handle this, mixed integer programming (MIP) was developed. This method only works if all the equations are linear. In contrast to LP, however, while an optimum solution can be generated, it may take too long. MIP does have a way to tell how much better an optimum solution would be if it could be generated.

Linear programming assumptions or approximations may also lead to appropriate problem representations over the range of decision variables being considered. At other times, though, nonlinearities in the form of either nonlinear objective functions or nonlinear constraints are crucial for representing an application properly as a mathematical program. Because of this, there come into existences non linear programming problems.

A general optimization problem is to select n decision variables \( x_1, x_2, \ldots, x_n \) from a given feasible region in such a way as to optimize (minimize or maximize) a given objective function \( f(x_1, x_2, \ldots, x_n) \) of the decision variables. The problem is called a nonlinear programming problem (NLP) if the objective function is nonlinear and/or the feasible region is determined by nonlinear constraints. Thus, in maximization form, the general nonlinear program is stated as:

Maximize \( f(x_1, x_2, \ldots, x_n), \)

subject to:

\[
g_1(x_1, x_2, \ldots, x_n) \leq b_1,
\]

\[
\ldots
\]

\[
g_m(x_1, x_2, \ldots, x_n) \leq b_m,
\]

where each of the constraint functions \( g_1 \) through \( g_m \) is given.
Many optimization problems involve integer or discrete variables and can be modeled as Mixed Integer Non Linear Programming Problems (MINLPs). These variables can variously be integer variables, modeling for example numbers of men, or zero–one variables modeling decisions, or discrete variables modeling, for example, equipment sizes. Binary variables play an important role in integer programming and are used widely in applications. They can be used to model decisions such as, at which level of discount slab, discount is applicable in procurement of goods. These variables are also very popular because of the placement for discrete or integer variables.

Methods for solving MINLP problems fall into two broad classes. The first class is formed by deterministic methods which gives enough time, provided the problem satisfies certain conditions such as convexity and terminate with a guaranteed solution or an indication that the problem has no integer solution. All deterministic methods have in common that they perform an exhaustive tree search with rules that enable them to limit the search to a sub tree. Heuristic methods form these conditional classes of methods. These methods do not provide a guarantee that on termination the incumbent is a minimizer. Any deterministic method that is applied to a problem which does not satisfy for instance a convexity assumption becomes a heuristic method. Though there are varieties of methods but Branch–and–bound method in particular has been very successful and underpins all the other methods. Branch–and–bound is a general frame work for solving integer and combinatorial problems. The combinatorial part of the problem (determining the optimal integer assignment) is solved by a tree search in which NLP relaxations of the MINLP problem are solved and non–integer NLP-solutions are eliminated by adding simple bounds (branching). By using lower and upper bounds it is possible to limit the tree search, thus avoiding complete enumeration. It is possible to interpret branch–and–bound as a clever rounding procedure which aims to produce an integer solution by “rounding” the fractional solution of the NLP relaxation. The methodology is presented for general MINLP problems. The particular problem which is considered in this work is

$$\min_{x} f(x)$$
$$subject to \ g(x) \leq 0$$
$$x \in X, x_i \text{ integer } \forall i \in I$$
where $f$ and $g$ are continuously differentiable convex functions and it is assumed that the feasible region is bounded, which can be achieved for instance by adding simple bounds on the variables. It is important to realise, that in general problem cannot be solved like an NLP problem. This is due to the integer restrictions on the variables. Even verifying that a given $x$ solves MINLP is not easy, since no optimality conditions exist for it that can be checked. Branch–and–bound gives a framework in which MINLP can be solved. In our thesis, in each chapter we have used Lingo software for solving the formulated MINLP SC procurement distribution coordination that uses branch and bound method. LINGO is a comprehensive software tool designed to provide solutions of Linear, Nonlinear (convex & non-convex/Global), Quadratic, Quadratically Constrained, Integer optimization models in a fast and efficient manner.

1.6 FUZZY SYSTEM MODELING AND SUPPLY CHAIN: AN OVERVIEW AND APPLICATIONS

This section provides a survey of the application of fuzzy set theory in SCM. Fuzzy set theory has been studied extensively over the past 40 years. Zadeh (1973) also states: “As the complexity of a system increases, our ability to make precise and yet significant statements about its behavior diminishes until a threshold is reached beyond which precision and significance (or relevance) become almost mutually exclusive characteristics. It is in this sense that precise quantitative analyses of the behavior of humanistic systems are not likely to have much relevance to the real-world societal, political, economic, and other types of problems which involve humans either as individuals or in groups.” Summarizing, the fuzzy system approach demonstrates many advantages in real-world applications that could be expressed as follows [Türk sen and Zarandi, (1999)]: (a) Fuzzy system models are conceptually easy to understand. (b) Fuzzy system models are flexible, and with any given system, it is easy to manage it with fuzzy system models or layer more functionality on top of it without starting again from scratch. (c) Fuzzy system models can capture most nonlinear functions of arbitrary complexity. (d) Fuzzy system models are tolerant of imprecise data. (e) Fuzzy system models can be built on top of the experience of experts. (f) Fuzzy system models can be
blended with conventional control techniques. (g) Fuzzy system models are based on natural languages. (h) Fuzzy system models provide better communication between experts and managers.

Usually SC systems contain several subsystems (like material flow, information flow, buyer-seller relations) with unlimited relations and interfaces. Each subsystem usually contains uncertainties. Petrovic et al. (1999) demonstrate the uncertainties in SC systems as: “a real SC operates in an uncertain environment. Different sources and types of uncertainty exist along the SC. They are random events, uncertainty in judgment, lack of evidence, lack of certainty of evidence that appear in customer demand, production and supply. Each facility in the SC must deal with uncertain demand imposed by succeeding facilities and uncertain delivery of the preceding facilities in the SC.” Clearly, uncertainties of each subsystem or element make the whole system uncertain. However, the nature of interfaces in SC systems causes an SC system to operate in a completely imprecise environment. These interfaces are embedded in the material flows, information flows, and supplier buyer relations. In the past four decades, material flows, which are related to inventory control and transportation, have been investigated by several researchers [Berry(1972); Blackstone et al. (1982); Finch and Cox (1989); Fogarty et al. (1991); Goyal and Gopalakrishnan (1996); Hariga (1998); Veral and Laforge (1990)]. Furthermore, information flows, Management Information Systems (MISs), Decision Support Systems (DSSs), manufacturing information systems, etc. have also been other areas of interest for several researchers [Blanchard and Fabrycky (1981); Jackson and Browne (1992); Murdick et al. (1990)]. Thus, in addition to its integrated perspective, what makes the new SC approach deals with relationships between different elements of such a chain [Maloni and Benton (1997)]. Moreover, relations between elements of the SC critically depend on human activities. This fact is one of the main reasons why emergent SC systems require fuzzy system modeling. Sugeno and Yasukawa (1993) state “fuzzy algorithms are nothing but qualitative descriptions of human action in decision making.” On the other hand, including several factors in the performance of an SCM system makes it complex. In other words, when a system uses a large amount of real data, its complexity grows exponentially. Thus, in SC system design and
modeling we are to build a large-scale system with limited abilities of quantitative approaches (Figure 1.5). Türksen (1992) states several reasons that involve the weakness of quantitative models: (i) of managers requirement of precise information; (ii) difficulties in understanding demand (iii) complexities in expressing the natural language of managers. The complexity of analyzing real systems increases because companies capture large amounts of data in data warehouses in this information age. Zimmermann (1996) believes that real situations cannot be described precisely and humans are not able to concurrently understand and analyze real systems. The main concept and definition of SC system is its holistic and realistic perspective. This gives it an advantage and makes the SC different from traditional reductionist approaches. As a matter of fact, the SC is not just a mathematical and theoretical approach, but a real-world problem analyzer and solver. In this regard, Zimmermann states: “The usefulness of the mathematical language for modeling purposes is undisputed. However, there are limits to the usefulness and possibility of using classical mathematical language, based on the dichotomous character of set theory, to model particular systems and phenomena in the social sciences”, [Zimmermann(1996)].

![Figure 1.5: Relation between Fuzziness Of SC System & Material and Information Flows](image)

**1.7 SUPPLY CHAIN COORDINATION: PERSPECTIVES & EMPIRICAL STUDIES**

SCM involves coordinating and integrating activities and processes among different business functions for the benefit of the entire SC (Figure 1.6). The integration of multiple functions and enterprises, particularly in a global SC context, is complex and requires coordination. Hence, coordination between elements of SC for improving its
Procurement-Distribution Coordination in Supply Chain under Quantity Discounts & Varying Truck Load Policies

performance has received a great deal of attention from researchers. Some coordination strategies, such as the quantity discount, credit option, and payback/return policy, are often used to regulate the relationship among parties involved in the SC.

![Diagram of Supply Chain Management](image)

Figure 1.6: Coordination in Supply Chain Management

Coordinating activities among members of a SC channel has been a subject of great attention. Among various methods to coordinate independent channel members, a number of studies in the literature suggest quantity discount as a mechanism to achieve incentive-compatible coordination between a seller/manufacturer and his buyer/retailer. The rationale behind this coordination mechanism is that a quantity discount schedule can be designed to align the player’s interests with the maximum channel gain. In a coordinated (or integrated) SC, a central decision-maker determines the capacity of both the supplier and manufacturer. The optimum manufacturer and supplier capacities are equal and therefore the central decision-maker problem can be cast as a single capacity investment decision with the following benefits.

1.7.1 Benefits & Studies of Coordination in Supply Chain

Coordination is realised when a decision maker in the SC, acting rationally, makes decisions that are efficient for the SC as a whole, [Gupta and Weerawat (2006)]. Companies forming a SC are dependent on the performance of other organisations.
The need to manage these dependencies and different resource flows is important for a company’s success, [Danese et al. (2004); Patnayakuni et al.(2006)]. SC coordination is a vehicle for redesigning decision rights, workflow, and resources between SC members to leverage improved performance, [Lee, (2000)]. Good coordination in the SC reduces uncertainty in manufacturing networks [Simatupang et al. (2004)], which in turn translates into reduced variability. Some authors argue that coping with uncertainty is the primary motivation for SC coordination, [Simatupang et al. (2004)]. SC coordination offers a means to understand and analyse a SC as a set of dependencies. These dependencies exist both in physical flow, which is the flow and storage of goods, and informational flow, which deals with the storage and flow of information associated with those goods, [Lewis and Talalayevski (2004)]. In the traditional design of interacting flows, when the physical flow has been the basis for designing the SC, information flow may result in inefficient decision-making and movement of information. Advances in information technology have made it possible to separate the design of information flow from the physical flow by, for example, shortening the information flow. By such changes, the number of decision points can be reduced and the quality of decisions can be improved.

Lee (2000) states that, “to coordinate material, information, and financial flows, companies must have access to information reflecting their true SC picture all the times.” In this approach, sharing of information and knowledge sharing are preconditions for commencing coordination. Only after these are realised, is coordination implemented. Coordination theory, instead, asserts that managing the information flow is one mechanism to realise SC coordination. Supplier and customer relationships are presented as an integration continuum in Figure 1.7, [Spekman et al., (1998)]. The model indicates how a supplier may develop into a partner. In the first stage, the relationship is based on price negotiations and an adversarial relationship. In the ‘cooperation stage’, long-term contracts are established, and the number of suppliers is actively reduced. In ‘coordination’, (the next stage), information linkages enable wider and more routine information exchange. In most SCs, all key supplier and customer relationships have achieved cooperation or coordination stages in their integration efforts.
1.8 SUPPLY CHAIN COORDINATION MODELS

Three categories of coordination can be defined as follows; Vendor-buyer coordination, Production-Distribution coordination and Procurement-Distribution coordination. The models are targeted at such issues as: selection of batch size, choice of transportation mode and choice of production quantity.

1.8.1 Vendor-Buyer Coordination

The vendor-buyer coordination problem is one of the classical research areas in the multi-echelon inventory literature. Within the large spectrum of existing work in this area, centralized and decentralized models can be considered as the two extremes. Classical multi-echelon inventory theory suggests integrating and modeling the decision problems of the vendor and the buyer together. This strategy qualifies as centralized modeling of the problem and, without any doubt, provides the best result in terms of total system cost (i.e., the global optimum). However, it requires that both the vendor and the buyer make their data available to the other party. In application, this may not be desirable unless both parties represent components of the same company. Furthermore, in real life, there is often a superior/subordinate relationship inherent in the situation where the dominant party prefers her/his priorities to lead the solution. As a result, decentralized modeling of the problem may be necessary. In a decentralized model, the parties solve their sub problems independently of each other with very limited sharing of information. As a consequence, the superior party’s priorities lead the solution. In most retail applications, the superior party is the buyer.
whereas in manufacturing applications the superior party is usually the manufacturer, i.e., vendor.

While classical vendor-buyer coordination models can generally be characterized as falling into one of the two extreme modeling approaches (i.e. centralized vs. decentralized), the current trend in SC research is towards investigating ways to apply decentralized models without sacrificing too many of the cost saving benefits that result from centralized models. For this purpose, channel coordination tries to identify the inefficiencies in decentralized solutions and to align the individual incentives for both parties with those of the centralized solutions. The output of channel coordination, i.e., the so-called coordinated solution, combines the benefits of the two extremes, i.e., centralized and decentralized solutions. However, the pure centralized and the pure decentralized modeling approaches are still important techniques for practical applications because the former sets a benchmark for cost minimization whereas the latter helps to identify opportunities for coordination.

1.8.2 Production-Distribution Coordination

Most consumer products flow through a pipeline that begins with production at a plant, followed by transportation to a retail outlet for consumer purchase, perhaps passing through a distribution center on the way. Most companies manage these two functions independently, with little or no coordination between production scheduling and distribution planning. This decoupled approach works acceptably well if there is sufficient finished goods inventory to buffer the production and distribution operations from each other.

However, the cost of carrying inventory and the trend to just-in-time operations is creating pressure to reduce inventories in the distribution channel. As a result of this pressure, many companies are exploring closer coordination along the manufacturing/distribution channel. For example, Johnson & Johnson is testing a linkage between their Band-Aid factory in North Brunswick, New Jersey, and a small retail chain, [Fortune (1990)]. Procter & Gamble and Wal-mart have also teamed up to coordinate better the flow of products between them.
It is becoming increasingly clear that companies will need to make the necessary organizational changes that will facilitate coordination of these operational functions and develop an ability to make more complex decisions within this structure. There is a small but growing body of management science research concerned in various ways with the coordination of production and distribution. Glover et al. (1979) developed a network flow model of the production scheduling, inventory and distribution decisions of Agrico Chemical. They embedded this model in a decision support system that was used to analyze both short-run planning decisions and long range strategic decisions, such as the sizing and location of distribution centers, the size of transportation equipment, and the nature of supply options.

1.8.3 Procurement-Distribution Coordination

SC planning is concerned with the coordination and integration of key business activities undertaken by an enterprise, from the raw material procurement to the distribution of finished products to customers. It is the set of activities that focus on evaluating demand for material and capacity, and formulate plans and schedules based on meeting the demand and company goals. Procurement and Distribution's role in SC is to optimize the purchase, storage and distribution of raw materials, work-in-progress or final products. Discount models have been used extensively in the past to achieve coordination between a buyer and a vendor in the context of SCM. Such models are based on the vendor offering a discount to the buyer so as to entice him to order in higher batch sizes. The solution is achieved at the point where the vendor is better off and the buyer is not worse off. The quantity to order at a given time must be determined by balancing two factors: (1) the cost of possessing or carrying materials and (2) the cost of acquiring or ordering materials. Purchasing larger quantities or economic order quantity may decrease the unit cost of acquisition, but this saving may not be more than offset by the cost of carrying materials in stock for a longer period of time. The economic order quantity (EOQ) is the amount of inventory to be ordered at one time for purposes of minimizing annual inventory cost. In other words, EOQ is that size of the order which gives maximum economy in purchasing any material and ultimately contributes towards maintaining the materials at the optimum level and at the minimum cost. The various factors that affects the procurement, distribution and inventory decisions are given in next sub sections.
1.8.3.1 Factors Affecting Procurement Decisions

Procurement is concerned with purchasing and arranging movement of materials, parts, and/or finished inventory from suppliers to manufacturing or assembly plants, warehouses or retail stores. Depending on situation, the acquisition process is commonly identified by different names. In manufacturing, the process of acquisition is typically called *purchasing*. In government circles, acquisition has traditionally been referred to as *procurement*. In retailing and wholesaling, *buying* is most widely used term. Although differences do exist concerning acquisition situations, the term procurement is used here to include all types of purchasing. The term *material* is used to identify inventory moving to an enterprise regardless of its degree of readiness for resale. The term *product* is used to identify inventory that is available for consumer purchase. In other words, materials are involved in process of adding value through manufacturing whereas products are ready for consumption as in retail.

Procurement is concerned with availability of the desired material assortments, where and when needed. Whereas physical distribution is concerned with outbound product shipments, purchasing is concerned with inbound materials, sorting, or assembly. Under most marketing situations, involving consumer products, such as a grocery supplier that ships to a retail food chain, the supplier’s physical distribution is the same process as a retailer’s procurement operations. Although similar or even identical transportation requirement may be involved, the degree of managerial control and risk related to performance failure varies substantially between physical distribution and procurement.

Procurement often requires very large shipments, which may use barge, deep water vessels, unit trains, and multiple truck loads to transport. While exceptions do exist, the typical goal in procurement is to perform transportation at the lowest cost. The lower value of materials and parts in contrast to finished products means that the greater potential trade-off exists between costs of maintaining inventory in transit and time required to use low-cost modes of transport. Since the cost of maintaining materials in supply pipeline is less per day than the cost of maintaining finished inventory, there is normally no benefit for paying premium rates for faster inbound transport. The case study in Chapter 2 (section 2.2) gives insights of this scenario.
Within a typical enterprise the three areas procurement, distribution and inventory of SC overlaps. Viewing each as an integral part of the overall value-adding process creates an opportunity to capitalize on the unique attributes of each while facilitating the overall process. The prime concern of an integrated SC process is to coordinate overall value-added inventory movement. The three areas combine to provide integrated management of materials and products moving between locations, supply sources, and customers of an enterprise.

Key challenges in today’s environment: The concept of procurement, the acquisition of goods, has been around for thousands of years. While the objectives in procurement have not dramatically changed, the ability to acquire a product at lowest possible costs while meeting the buyer’s needs in terms of quality, quantity and time, has become increasingly complex. This is often due to a variety of issues that are intrinsically related to the SC. These include:

* Sustainability: Transport is the fastest growing source of greenhouse emissions and is estimated to be responsible for >20% of carbon dioxide emissions in the future. With the introduction of the carbon tax the costs to supply could change dramatically. 

* Globalisation: Products are being sourced globally to take advantage of such elements as labour rates and specialised manufacturing, impacting lead times and inventory requirements.

* Vulnerability: Business decisions to dramatically reduce working capital, consolidate the supply base and outsource operations reduce ‘buffers’ to react to unplanned changes. This is in a time where the risk of environmental issues (e.g. natural disasters) appears to also be increasing.

* Product Proliferation and Reduction in Life-Cycles: The variety of products offered often increases the number of inputs and suppliers, while the typical life cycle of a product has decreased causing increased product (and material) write-offs/downs.

* Business alignment: Customer requirements (e.g. multi-channel, many variants) often conflict with internal objectives (e.g. lean) and supplier capabilities requiring procurement to play a balancing act with stakeholders.
1.8.3.2 Factors Affecting Transportation Decisions

Transportation refers to the movement of product from one location to another as it makes its way from the beginning of a SC to the customer’s hands, [Chopra and Meindl (2007)]. Any costs affecting transportation decisions are as follows:

- **Vehicle-related cost.** This is the cost a carrier incurs for the purchase or lease of the vehicle used to transport products.

- **Fixed operating cost.** This includes any cost associated with terminals, airport gates, and labour that are incurred whether vehicles are in operation or not.

- **Trip-related cost.** This cost includes the price of labour and fuel incurred for each trip independent of the quantity transported.

- **Quantity-related cost.** This includes loading/unloading costs and a portion of the fuel cost that varies with the quantity being transported.

- **Overhead cost.** This includes the cost of planning and scheduling a transportation network as well as any investment in information technology.

All above costs are considered in the work presented as component of transportation cost. To achieve the objective of distribution network, we used direct shipment and cross docking strategies to distribute products to customers. **Direct shipment is** the strategy in which items or products are directly shipped from the supplier to the retailer stores without going through distribution centers. The advantages of this strategy are that retailers avoid the expenses of operating a distribution centre. Otherwise, the disadvantages are risk-pooling effects, the manufacturer and distributor transportation costs increase. This strategy is common if the retailer store requires fully loaded trucks, which implies that the warehouse does not help in reducing transportation cost. This is also common if the lead time is critical and the retailer has bargaining power.

In **Cross-docking** system, warehouses function as inventory coordination points rather than as inventory storage points. Goods arrive at warehouses from the manufacturer, are transferred to vehicles serving the retailers and are delivered to the retailers as rapidly as possible. Goods might spend less than 12 hours in the warehouses. This
strategy needs significant and difficult efforts to manage. For example, a fast and responsive transportation system is necessary for a cross-docking system to work. Forecasts are critical, necessitating the sharing of information. DCs, retailers and suppliers must be linked with advanced information system to ensure that all pickups and deliveries are made within the required time windows.

Above strategies are accomplished by various modes of transportation include water, rail, intermodal, truck, air, and pipeline & package carriers. Water is typically the least expensive mode but is also the slowest whereas air & package carriers the most expensive & the fastest. Rail & water are best suited for low-value large shipments that do not need to be moved in a hurry. Air & package carriers are best suited for small, high-value, emergency shipments. Intermodal Truckload carriers are faster than rail & water but somewhat more expensive. Less-Than- Truckload (LTL) carriers are best suited for small shipments that are too large for package carriers but much less than a Truckload (TL). A carrier’s decisions are also affected by the responsiveness it seeks to provide its target segment & the prices that the market will bear. Different modes of carriers are explained as under:

**Air Carriers**: The primary advantage of airfreight is the speed. Airfreight is costly and also must be combined with trucks to provide door to door service. Consequently, products best suited for this mode are of high value and/or extremely perishable. Although airfreight volume has increased over the past two decades, most shippers still regard this mode as premium emergency service. Major airlines like American, United and Delta that carry both passenger and cargo have a high fixed cost in infrastructure and equipment. Labour and fuel costs are largely trip related and independent of cargo carried on a flight.

**Trucks**: Trucks are the most flexible mode of transportation and account for approximately 80 percent of transportation expenditures. The mode offers the advantage of point to point service, over any distance, for products of varying weight and size. Compare to other modes, service is fast and reliable, with low damage and loss rates. Trucks can be divided into two categories (1) TL & LTL. In TL transportation, the cost is a fixed of one truck up to a given capacity. In this mode
company may use less than the capacity available but cost per truck will not be
deducted. However in some cases the weighted quantity may not be large enough to
substantiate the cost associated with a TL mode. In such situation, a LTL mode is
used. LTL is be defined as a shipment of weighted quantity which does not fill a
truck. In such case transportation cost is taken on the bases of per unit weight.

**Rail:** Rail carriers once dominated the transportation sector, but their share of
transportation market has declined steadily since World War II. Rail carriers are
relatively inflexible and slow and have higher loss and damage rates, compared to
truck carriers. However, rail has the advantage of lower variable operating costs,
which makes it attractive for hauling large tonnage over long distances.

**Intermodal:** Intermodal transportation is the use of more than one mode of transport
to move a shipment to its destination. A variety of intermodal combinations are
possible, with the most common being truck and rail. Intermodal traffic has grown
considerably with the increased use of containers for shipping and the rise of the
global trade.

### 1.8.3.3 Factors Affecting Inventory Decisions

The importance of inventory management and the need for the coordination of
inventory decisions and transportation policies, has long been evident. Unfortunately,
managing inventory in complex SCs is typically difficult, and may have a significant
impact on the customer service and SC system wide cost. A typical SC consists of
suppliers and manufacturers, who convert raw materials into finished products, and
distribution centers and warehouses, from which finished products are distributed to
customers. That is inventory appears in the SC in the forms: raw material inventory,
work–in–process inventory and finished product inventory. Each of these needs its
own inventory control mechanism and determining these mechanism is difficult
because efficient production, distribution, and inventory control strategies that reduce
system wide cost and improved service levels must take into account the interactions
of the various levels in the SC. Nevertheless, the benefits of determining these
inventory control mechanism can be enormous. Now the question is why to hold
inventor. The reasons can be:
1. Unexpected changes in customer demand. Customer demand has always been hard to predict, and uncertainty in customer demand has increased in the last few years due to
   a. The short life cycle of an increasing number of products. Therefore the historical data about customer demand may be quite limited or may not available at all.
   b. The presence of many competing products in the market place. This proliferation of products makes it increasingly difficult to predict demand for a specific product.

2. The presence in many situations of a significant uncertainty in the quantity and quality of the supply, supplier costs, and delivery times.

3. Even where there is no uncertainty in the demand it is necessary to hold inventory due to delivery lead time

4. Economies of scale offered by transportation companies that encourage firms to transport large quantities of items, and therefore hold large inventories.

The Key factors that affect inventory policies are:

1. First and foremost is customer demand, which may be known in advance or may be random.

2. Replenishment lead time, which may be known at the time we place the order, or may be uncertain.

3. The number of different products.

4. The length of the planning horizon.

5. Costs, including order cost and inventory holding cost.
   a. Order consists of cost of product and transportation cost.
   b. Inventory holding cost consists of state taxes, property taxes, insurance of inventories, maintenance costs, obsolescence cost (when an item lose some of its value due to change in market scenario) and the opportunity costs (i.e. the return on investment that one would receive had money been invested in something else instead of inventory)
1.8.3.3.1 Some Basic Models

The classical economic lot size model, introduced by Ford W. Harris in 1915, is a simple model that illustrates the trades-offs between ordering and storage costs, considering a single warehouse facing a constant demand for a single item. Warehouse orders from the supplier, who is assumed to have an unlimited quantity of the product. The model assumes the following:

- Demand is constant at the rate of $D$ items per day.
- Order quantities are fixed at $Q$ items per order.
- A fixed set up cost $K$, is incurred every time the warehouse places an order.
- An inventory carrying cost (or holding cost) $h$, is accrued per unit held in inventory per day.
- The lead time, that is the time that elapses between the placement of an order and its receipt is zero.
- Initial inventory is zero.
- The planning horizon is infinite.

Our goal is to find the optimal order policy that minimizes annual purchasing and carrying costs while meeting all demands (without shortages). This is an extremely simplified version of a real inventory system. The assumption of a known fixed demand over a long horizon is clearly unrealistic. Replenishment of product is very likely take several days, and the requirement of a fixed order quantity is restrictive. Surprisingly the insight derived from this model will help us to develop inventory policies that are effective for more complex realistic systems. An optimal policy of the model described above, order should be received at the warehouse precisely when the inventory level drops to zero. This is called zero inventory property, which can be observed by considering a policy in which orders are placed and received when the inventory level is not zero. Clearly a cheaper policy would involve waiting until the inventory is zero before ordering, thus saving on holding costs.

To find the optimal ordering policy in the economic lot size model, we consider the inventory level as a function of time. We refer to the time between two successive replenishments as a cycle time. Thus the total inventory cost in a cycle of length $T$ is:
\[ K + \frac{hQT}{2} \]

Since the fixed cost is charged once per order and holding cost can be viewed as the product of the per unit per time period holding cost, \( h \); the average inventory level, \( Q/2 \); and the length of the cycle, \( T \). Since the inventory level changes from \( Q \) to 0 during a cycle of length \( T \), and demand is constant at a rate of \( d \) units per unit time, hence \( Q=TD \). The average cost per unit of time;

\[ \frac{KD}{Q} + \frac{hQ}{2} \]

Differentiating above function w.r.t \( Q \) and equating to zero we get:

\[ Q^* = \sqrt{\frac{2KD}{h}} \]

This quantity is referred to as the Economic Order Quantity (EOQ)

Now we consider multi facility SC that belongs to a single firm where the objective of the firm is to manage inventory so as to reduce system wide cost; thus, it’s important to consider the interaction of the various facilities and the impact this interaction has on the inventory policy that should be employed by each facility. So consider a retail distribution system with a single supplier serving a number of retailers. With the following assumptions:

1. Inventory decisions are made by a single decision maker whose objective is to minimize system wide cost.

2. The decision maker has access to inventory information at each of the retailer and at the warehouse of supplier.

Under these assumptions, an inventory policy based on the so called echelon inventory is an effective way to manage the system.

In a distribution system, each stage or level (i.e. the warehouse or the retailer) often is referred to as an echelon, plus all downstream inventories. For example, the echelon
at the warehouse is equal to the inventory at the warehouse, plus the entire inventory in transit to and in stock at the retailers. Similarly the echelon inventory position at the warehouse is the echelon inventory at the warehouse, plus those items ordered by the warehouse that have not yet arrived.

The present work has developed models on the basis of quantity discounts models of inventory management i.e. on the basis of all units and incremental quantity discount model. In all unit quantity discount model, discount is availed on every product that is purchased after the purchased quantity exceeds the given level whereas in incremental discount model discount is provided on incremented units where discounts are offered only for products which are in excess of specified quantity. Quantity discounts are generally to increase the sales of the product, reducing the in-hand inventory by increasing the sales, better procurement planning, lower order processing cost, reducing the transportation cost by making use of the discounts offered by the trucking industry etc. A discount is lot size-based if the pricing schedule offers discounts based on the quantity ordered in a single lot. A discount is volume-based if the discount is based on the total quantity purchased over a given period (e.g. a year), regardless of the number of lots purchased over that period. In this research we consider a firm (retail/department chain) that procures bulk commodity from markets to further distribute it downstream to a set of identical retailers of its chain. Since the firm purchases in bulk, thereby it is offered by volume based discounts by suppliers. The third party transporter also offers discounts/ policies on freight distribution. Thereby retailer is enticed to purchase due to dual advantage.

Above were the various factors affected the procurement-distribution coordination in SC. The wealth of research into this work is impressive and confirms its continuing importance as a research topic, which is presented in next section.

1.8.3.4 Literature Survey of Procurement & Distribution Models

A brief review of closest literature associated with this research is presented in this section in the field of transportation systems and quantity discounts. The literature in this area discusses mainly about the TL inventory models, LTL inventory models, economies of scale in quantity price, and discounted freight cost.
Many authors have researched inventory models, considering various assumptions and solved the inventory problem by different methods. In 1913, Harris (1913) addresses a practical industrial problem of finding the lot size of each order such that the overall costs associated with manufacturing a unit of the product is minimized. The formula developed by Harris forms the basis of all economic order quantity models. Vassian (1955) finds an optimal inventory policy for periodic inventory models to satisfy the requirement of a particular management. Morse (1958) extended the work done by Vassian (1955) by assuming the system to be stochastic and analyzed the effect changes in the inventory policy. Extension of the classical economic order quantity model to economies of scale is performed by Buffa and Miller (1979), McClain and Thomas (1985), Silver and Peterson (1985). While Lee (1986) considers freight discount instead of quantity discount, he considers the practical situation where the freight cost is discounted whenever a large shipment is placed. The assumptions made by Lee (1986) are same as the classical economic order quantity model developed by Harris (1915), except for the set-up cost structure. The author considers the set-up cost a sum of fixed cost and freight cost with discounts, which implies that the set-up cost depends upon the quantity ordered. The higher the quantity the lower will be the set-up cost. The authors of Lee (1986) & Hadley and Whitin (1963) discuss about the individual impact of price discount and freight discount on inventory policy. Hwang, Moon, and Shinn (1990) discuss the combined effect of price and freight discount on an inventory policy. Whenever an order is placed price discount is offered, so it is profitable to buy large quantities of the product, at the same time the freight cost also decreases due to large shipment size. Providing price and freight discount will increase the ordering quantity, there by having a heavy impact on inventory policy.

Lancaster (1966) and Quandt (1966), discuss about various transportation choices, their advantages, disadvantages and common practices in the shipping industry. Baumol and Vinod (1970) explains the importance of transportation choices made by shippers, whereby order quantity and transportation alternative can be jointly determined. The optimal choice of mode is shown to involve a trade-off among freight rates, speed, dependability, and en-route losses. They also prove that faster and more dependable
service simply reduces the safety stock and the in-transit inventory for a shipper or receiver. The authors develop a model which will help in statistical comparison of the different modes of transportation by using the four attributes mentioned below, thereby the ordering quantity and the transportation alternative is jointly determined. The four attributes used in the development of the model are: shipping cost per unit (including freight rate, insurance, etc.), mean shipping time, variance in shipping time, carrying cost per unit of time while in transit (interest on capital, pilferage and deterioration). Das (1984) presents a model for finding the economic order quantity when the supplier offers quantity discounts while formulating the inventory holding cost. The author considers only the cost incurred due to the in-transit inventory and cycle inventory and does not consider the cost incurred due to safety stock. This model is also studied from the supplier’s point of view by Monahan (1984), who designs the procedures for determining the optimum discount schedule for the supplier. Model developed by both Das and Monahan assumes that the demand rate for the product is known and constant. Abad (1988,[1]) assumes the demand to be stochastic and develops a model for determining the optimal selling price and lot-size, while all-unit quantity discounts are offered by the supplier. The author also analyzes the problem for incremental quantity discounts and discusses in Abad (1988 [2]). Benton and Park (1996) give a classification literature on all the research done in the field of quantity discounts. Munson and Rosenblatt (1998) analyze thirty nine firms that receives/offers quantity discounts. The result of the study indicates that eighty three percent of the buyers receive quantity discounts for most of the items they purchase, which illustrates the prevalence and importance of quantity discounts in practice.

Rieksts and Ventura (2003) determines the optimal inventory policy with two modes of freight transportation. The author considers two transportation choices, i.e. TL and LTL transportation. Mendoza and Ventura (2004) extends the work by Rieksts and Ventura (2003) to all-unit quantity discounts and finds the optimum ordering quantity that minimizes the total annual cost.

Our objective in this research is to enhance the efficacy of supply chain by developing procurement and distribution policies that incorporate information observed in the markets due to discounts and freight policies.
The thesis is divided into the following chapters:

**Chapter 1** : Introduction

**Chapter 2** : Single Source- Single Destination Coordination

**Chapter 3** : Single Source- Multiple Destination Coordination

**Chapter 4** : Multi Source- Multi Destination Coordination

**Chapter 5** : Two Stage Single Source- Multiple Destination Coordination

We now briefly describe the composition of each chapter of the thesis.

### 1.9 STRUCTURE OF THESIS

The work presented in this thesis focuses on some contributions to modeling in Procurement - Distribution Coordination in SCM. The performance of the proposed models is shown with the Lingo 11.0 programming and model validations on real life data sets existing in retail firms. The results obtained are encouraging and close to the actual values.

**Chapter -1** is introductory and explains the overview and basic concepts of SCM and optimization techniques related to the understanding of the research work. The existing research and applicability of the research carried in the thesis in procurement-distribution coordination is highlighted in this chapter. Rest of the thesis is organized into four chapters as follows:

**Chapter-2** “Single Source- Single Destination Coordination” considers the problem of a single source supplying multiple products at a single destination. In Section I, we have developed mathematical models to compute optimal order for integrated procurement-transportation problem of SC with two modes of transportation namely, TL and LTL carriers by introducing all unit and incremental quantity discount structure into analysis. Finite planning horizon and dynamic demand is assumed to make ordering decisions. Section 2 of the chapter incorporates quantity discounts and freight policies for multi items that are perishable in nature, which are supplied from single source to single destinations under fuzzy environment. It is assumed that, single
source or a supplier is offering various discounts on the purchase of quantity and are supplying to a destination. A transporter hired by the buyer also offers different policies to choose on distribution of products, thereby buyer is enticed by dual benefit on procurement as well as distribution. A fuzzy optimization problem is converted to crisp mathematical programming problem using triangular membership function. The problems are solved and cases are presented in both sections to validate the model.

**Chapter-3** “Single Source- Multiple Destination Coordination” considers transportation from single source to multiple destinations. The model in Section I is targeted towards computing optimal order for integrated procurement-distribution problem. It incorporates quantity discounts and freight policies for multi items that are perishable in nature, which are supplied from single source to various destinations. It is assumed that there is finite planning horizon and dynamic demand to make ordering decisions. Section II incorporates quantity discounts and freight policies for multi items that are perishable in nature, which are supplied from single source to multiple destinations under fuzzy environment. It is assumed that, there is finite planning horizon on which demand and total costs are fuzzy in nature. A fuzzy optimization problem is converted to crisp mathematical programming problem using triangular membership function. The real life cases are discussed to validate the procedures.

**Chapter-4** “Multi Source- Multi Destination Coordination” discusses multi source multi-destination procurement-distribution SC in which a model is proposed to compute optimal ordered quantities for the integrated procurement-distribution problem with all unit discounts on quantity ordered and shipping that discounted quantity with two modes of transportation, TL & LTL in Section I. A finite planning horizon and deterministic demand is assumed to make ordering decisions. Section II develops coordinated quantity and freight discount policy for perishable products under uncertain cost and demand information i.e. fuzzy nature. The fuzzification grants authenticity to the model in the sense that it allows vagueness in the whole setup which brings it closer to reality. A case is provided to validate the procedure.

**Chapter-5** “Two Stage Single Source- Multiple Destination Coordination” considers the dynamics of two stage SC where, there is single source of supply, an intermediate
stoppage, single distributor and multiple destinations of consumption i.e. the integration of procurement and distribution decision making under two stage environment. Different discount policies are offered to procure and transport goods from the one stage to other stage when it is assumed that inventory carrying charge at the stoppage is very high after a pre-specified time. Model will benefit organizations in a long run by helping them determining optimal quantity to be ordered which not only reduces the cost of procurement and transportation costs. A case is presented to testify and validate the procedure. Section II describes the model with uncertainty in demand and cost, when procurement and distribution decisions of SC need to be taken. The model incorporates a single supplier transporting its products to multiple destinations of a retailer. This process becomes tedious, when items are moving with stoppage as on stoppage point inventory carrying cost would also be incurred due to perishable nature of products. Different discount policies are offered to procure and transport goods from the one stage to other stage. By using the fuzzy set theory, optimum decisions are taken and a case is presented to validate the procedure.

Conclusion of the work done, scope of future research and a reference list is given at the end of the thesis. This thesis is based on the following research papers in the order of appearance in the thesis:


