Development of Decision Support Systems for the Design of Supply Chain Management Drivers

THESIS

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Dedicated

To my Parents– Mr. Braja Kishore Routroy & Mrs. Shanti Lata Routroy:

Epitome of sacrifice

To my father and mother -in-law- Mr. Basanta Kumar Das & Mrs. Susma Das:

Epitome of courage

To my Wife – Mrs. Tanima Rani Routroy (Mani):

Epitome of sincerity

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CERTIFICATE

This is to certify that the thesis entitled **"Development of Decision Support Systems for the Design of Supply Chain Management Drivers"** and submitted by **Srikanta Routroy,** ID. No. 2001PHXF016 for award of Ph.D. Degree of the Institute, embodies original work done by him under my supervision.

Signature of the Supervisor R.B. Kodali

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ABSTRACT

Supply chain management has been recently introduced to address the integration of organizational functions ranging from the ordering and receipt of raw materials throughout the manufacturing processes, to the distribution and delivery of products to the customer. Its application demonstrates that this idea enables organizations to achieve higher quality products, better customer service, and lower inventory cost. The supply chain drivers play a significant role in supply chain management's ability to support a firm/organization's competitive strategy to maintain the competitive advantage. The supply chain management drivers are: facilities, transportation, information and inventory. Therefore, there is need for the development of decision support systems for design of supply chain management drivers.

The objective of the proposed research is to develop and validate the decision support systems for the design of supply chain management drivers. The drivers are facilities, transportation, information and inventory. Decision support systems are developed for the design of facilities driver in SCM. The facilities driver consist the decisions regarding location, capacity, warehousing methodology and manufacturing systems. The decision support system i.e. performance value analysis model is developed for selection of facilities location and also decision support system framework is developed for facilities location and it consists of qualitative analysis and cost analysis. The qualitative analysis is carried out by analytical hierarchy process model. The decision support system framework is developed for selection of capacity. The framework consists of analytical hierarchy process, integer programming and simulated annealing algorithm for selection of capacity. The decision support system framework is developed for warehouse methodology. The framework consists of

constant sum model and integer programming for warehouse methodology. The decision support system i.e. analytical binary model is developed for selection of manufacturing systems.

Decision support system framework is developed for design of transportation driver in SCM. It consists of ELECTREE III for selection of mode, route and network, logistics and PROMETHEE II for selection of carrier. Decision support system framework is developed for design of information driver in SCM. Differential evolution algorithm and simulation model is developed for supply chain inventory planning and optimization tool of MATLAB 6.1 is used for supply chain inventory planning in SCM. The simulation model is also developed for inventory performance measures in SCM. Integer programming is developed for the design of supply chain network.

The present research is an attempt to outline the significant features of the decision support systems for design of supply chain management drivers.

Chapter 1
Introduction

1.1 Overview

Stern *et al.* (2001) defined "a supply chain is the set of entities that collectively manufactures a product and sells it to an endpoint". The definition of a supply chain is in many cases very wide and not always easy to narrow down. Furthermore the definition often tends to vary from one person to another. In fact the view should differ from one company to another depending on different situations because the activities that make one company successful will not work for another (Ayers, 2000). All organizations have supply chains of varying degrees, depending upon the size of the organization and the type of product manufactured. These networks obtaining supplies and components, transform the raw materials into finished products which are then distributed to the customer (Svensson, 2002).

Evidences show that supply chains were present from the time when mankind understood the need of merchandising and distribution. There are several examples of success achieved in battles and wars of ancient history due to supply chain management. During World War II, military forces made effective use of supply chain management to ensure that the required material was at the right place at right time. A war could be lost if the weapons, food and supplies did not reach to the soldiers in time. Strategically, supply lines were cut off in order to cause havoc in enemy camps. The first supply chain ever could be traced down to the ancient times when barter system was used. In this system, one product was traded for another product of equal value. Later in 300 BC, Caesar made trading posts in East Asia in order to promote trade. This was the first retailer-supplier relationship establishment of the silk route to India (Johnson and Pyke, 2000).

The era from the mid-20th century to present can be roughly broken down into three phases. The first phase was from 1960 to 1975, in the development of contemporary go-to-market strategy. The phase was an inventory push environment in which the stock was pushed out to the distribution centres from the central supply that focused primarily on physical distribution of finished goods. The companies managed manufacturing work-in-process and raw materials as separate parts of the business. The production output was cascaded down to finished goods locations and management's task was to balance production output with customer requirements. The second phase was from 1975 to 1990. In this phase business leadership began to recognize the importance of integrating operations within the enterprise. During this period, companies harnessed increasing amounts of computer horsepower to the material outflow process. Management information systems priorities shifted from a focus on the financials to materials management techniques like Materials Requirement Planning and Manufacturing Resource Planning. The management priorities shifted to balancing raw material, work-in-process, finished goods inventory, and multiple customer service measures. Some progressive industries started shifting from an inventory push to a customer pull channel as power began to move downstream to the customer. The customer demand triggered the pulling of product from the central supply. The third phase started in late 1980s and has accelerated into this decade. In 1981, IBM outsourced almost all of its activities and built a full computer. Wal-Mart introduced the concept of cross docking and replaced K-Mart as the leader in retail stores in 1985. Effective use of computers revolutionized the business process in 1990. Internet revolutionized the information pathway and the distribution system of the business in 1996. This latest evolution is based on the realization that the significant increase in productivity can only come from managing relationships, information, and material flow across enterprise borders. This is called supply chain management. It is defined as a set of approaches to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements (David *et al.*, 2000).

1.2 Need of decision support systems for supply chain drivers

Clearly, like many complex business systems, supply chain management problems are not so rigid and well defined that they can be delegated entirely to computers. Instead, in almost every case, the flexibility, intuition and wisdom that are unique characteristics of the humans are essential to manage the system effectively. A decision support systems (DSS) is a system under the control of one or more decision makers that assists in the activity of decision making by providing an organized set of tools intended to impose structure on portions of the decision-making situation and to improve the ultimate effectiveness of the decision outcome. The DSS clearly offers management a powerful tool and is rapidly becoming an integral component of managerial work. The speed with which today's information becomes yesterday's news continues to increase at a staggering rate. Tomorrow's manager will confront an ever-narrowing window of opportunity within which effective decisions will need to be made. Deadlines will be measured in days, hours, and minutes rather than in quarters, months, and years. The leveraging of technology that will allow tomorrow's manager to be effective in such a high-speed environment is what decision support is all about. To meet the demands of managerial work, a DSS must be able to provide the decision maker with certain key elements vital to his or her success. Its effectiveness depends on the degree of fit between the decision maker, the context of the decision, and the DSS itself. The potential benefits of DSS are as follows:

- Extend the decision maker's ability to process information and knowledge.
- Extend the decision maker's ability to tackle large-scale, time-consuming, complex problems.
- Shorten the time associated with making a decision.
- Improve the reliability of a decision process or outcome.
- Encourage exploration and discovery on the part of the decision maker.
- Reveal new approaches to thinking about a problem space or decision context.
- Generate new evidence in support of a decision or confirmation of existing assumptions.
- Create a strategic or competitive advantage over competing organizations.

The DSS is expected to extend the decision maker's capacity in processing the mountain of information involved in making a decision. Further, many components of a decision situation, although structured, are highly complex and time-consuming. The DSS can solve those portions of the problem, and save on cognitive resources and, more importantly, large blocks of precious time for the decision maker. As a result, using a DSS can be expected to decrease the overall time involved in reaching a complex, unstructured decision. Additional benefits can be found in the area of innovation and creativity. Simply using the DSS can provide the decision maker with potential alternatives that might otherwise go unnoticed or appear too complex and difficult to pursue. The tools within the DSS can stimulate the problem solver to reach innovative insights regarding solutions and their associated outcomes. In addition, the output of the DSS may often justify the position of the decision maker(s), thus facilitating consensus among stakeholders. Finally, given the shrinking window of opportunity associated with the pace of business, the DSS may provide competitive advantage to organizations. To achieve some or all of these potential benefits, however, the manager must understand not only the appropriate application of a particular decision support tool but also its limits.

Decision support system for supply chain management (SCM) is a fast growing sector of logistics software industry (Desutch, 1996). In 1993, Procter and Gamble (P&G) started a program of supply redesigning its entire chain, which would lead to lower costs (Jacobs et. al., 1995). Working with faculty from university of Cincinnati, P&G engineers developed a DSS to aid the teams involved in decision making. Amoco Chemical Corporation was confronted with a set of common inventory management challenges: identifying appropriate inventory levels at different locations in the supply chain, dealing with capacity constraints of capital, equipment and people, and conflicting organizational objectives among sales, production and inventory. The objectives of the cooperation include: relocate working capital to fund growth, maintain or improve customer service levels and improve operational efficiency. Mercer Management Consulting Inc. and Amoco developed a customer DSS to address these issues (Bausch *et al.*, 1995). It is obvious that supply chain manager has to take many decisions along the supply chain and the success of the SCM depends upon their drivers i.e. facilities, transportation, information and inventory (Chopra and Meindl, 2003). For any particular problem or issue of the driver, managers have to apply analysis or decision support tools for decision making. The supply chain drivers play a significant role in supply chain management's ability to support a firm/organization's competitive strategy to maintain the competitive advantage.

Therefore, there is a need for development of decision support systems for the design of supply chain management drivers.

1.3 Objectives of the Research

The objective of the proposed research is to develop and validate the decision support systems for the design of supply chain management drivers. The drivers are facilities, transportation, information and inventory. The objective of the research is achieved by following objectives:

- Decision support systems are developed for the design of facilities driver in SCM. The facilities driver consist the decisions regarding location, capacity, warehousing methodology and manufacturing systems.
    - The decision support system i.e. performance value analysis model is developed for selection of facilities location and also decision support system framework is developed for facilities location and it consists of qualitative analysis and cost analysis. The qualitative analysis is carried out by analytical hierarchy process model.
    - The decision support system framework is developed for selection of capacity. The framework consists of analytical hierarchy process, integer programming and simulated annealing algorithm for selection of capacity.
    - The decision support system framework is developed for warehouse methodology. The framework consists of constant sum model and integer programming for warehouse methodology.
    - The decision support system i.e. analytical binary model is developed for selection of manufacturing systems.

- Decision support system framework is developed for design of transportation driver in SCM. It consists of ELECTREE III for selection of mode, route and network, logistics and PROMETHEE II for selection of carrier.
- Decision support system framework is developed for design of information driver in SCM.
- Differential evolution algorithm and simulation model is developed for supply chain inventory planning and optimization tool of MATLAB 6.1 is used for supply chain inventory planning in SCM. The simulation model is also developed for inventory performance measures in SCM.
- Integer programming is developed for the design of supply chain network.

The present research is an attempt to outline the significant features of the decision support systems for design of supply chain management drivers.

1.4 Arrangement of Thesis

Chapter two discusses the literature review. Design of facilities driver in supply chain management is discussed in chapter three. Chapter four describes the design of transportation driver in supply chain management. Design of information driver in supply chain management is discussed in chapter five. The chapter six describes the design of inventory driver in supply chain management. Design of supply chain network is discussed in chapter seven. Chapter eight summarises the research contributions with conclusions.

References

[1] AYERS, J. (2000), "A primer on supply chain management", *The Executive's Journal*, vol. 16, no. 2, pp. 6-15.

[2] BAUSCH, D. O., G. G. BROWN, and DRONE (1995), "Consolidating and dispatching truck shipments of Mobil heavy petroleum products", *Interfaces*, vol. 25, pp. 1-17.

[3] CHOPRA, S. and MEINDL, P. (2003), Supply chain management: Strategy, Planning and Operation, Second Edition, Pearson Education, Asia.

[4] DESUTCH, C. H. (1996), "New software manages supply to match demand", New York Times, vol. 6, pp. 16-25.

[5] JACOBS, D. A., SILAN, M. N., and CLEMSON, B. A. (1995), "An Analysis of alternative locations and service areas of American red cross blood facilities", *Interfaces*, vol.25, pp.40-50.

[6] JOHNSON, M E., PYKE, D. F. (2000), "Introduction to the special issue on teaching supply chain management", *Production and Operations Management*, vol. 9, no. 1. pp.2-18.

[7] LUMMUS, R. R. and VOKURKA, R. J. (1999), "Defining supply chain management: a historical perspective and practical guidelines", *Industrial Management Data Systems*, vol.99, no. 1, pp. 11-17.

[8] STERN, L.W., ELANSARY, A. I., COUGHLAN, A. T. AND ANDERSON, E. (2001), Marketing Channels, Prentice Hall, Upper Saddle River, New Jersey.

[9] SVENSSON, G. (2002), "The theoretical foundation of supply chain management-A functionalist theory of marketing", *International Journal of Physical Distribution and Logistics Management*, vol. 32, no.9, pp. 734-754.

Chapter 2

Literature Review

2.1 Introduction

Intense competition in today's economy, the shrinking life cycles of products, superior product quality, excellent customer service, expanded variety, and high expectations of customers have forced business enterprises to focus their attention on correctly controlling their supply chains. Coupled with the continuing advancement in rapid information exchange, these have motivated the ceaseless development of supply chain knowledge and techniques to manage it. In a typical supply chain, raw materials are procured, products are manufactured at one or more factories, shipped to warehouses for intermediate storage and then shipped to retailers or customers. So the supply chain consists of suppliers, manufacturing centers, warehouses, distribution centers and retail outlets as well as raw materials, work in progress inventory and finished products that flow between facilities. The effective management of this chain so that product is produced and distributed at the right time, at right quantities and to the right locations in order to minimize the total system wide cost while satisfying service level requirements is known as supply chain management. Therefore, in today's markets, no business can be successful without mastering the issues, problems and possibilities in managing supply chains. That is why SCM has become an important topic of discussion among managers and academicians alike.

2.1.1 Evolution of SCM

The literature suggests that SCM has its roots in the evolutionary path followed through materials management and physical distribution after World War II, functional logistics (different mangers for all functions), and integrated logistics (one manger for all functions). Forrester (1958) justified the first step beyond functional logistics by using a system analysis approach to describe the forces that determine growth, fluctuation, and decline. He developed a complete company model that describes the flows of information, materials, manpower, capital, equipment and money. Bowersox (1969) discussed the evolution of integrated logistics and touches upon what will become known as the supply chain. He states that related responsibilities seldom terminate when product ownership transfer occurs and that firms are linked together in cooperative vertical marketing systems providing total supply chain performance. Langley (1992) suggested four stages of development: (i) cost control, (ii) profit center orientation recognizing the positive impact on sales, (iii) view of logistics as key to product differentiation, and (iv) as a principal strategic advantage. Masters and Pohlen (1994) described the evolution of logistics into three phases: (i) functional management (1960-70) – functions such as purchasing, shipping and distribution are each managed separately, (ii) internal integration (1980s) – the management of supply chain functions of a single facility are unified and become the responsibility of a single individual and (iii) external integration (1990s)– the management of supply chain functions throughout the chain are unified requiring cooperation and co-ordination between links in supply chain. Lalonde (1996) described the evolution of integrated logistics in three phases (i) physical distribution – the distribution of the goods is all that needs to be managed by a logistics manger, (ii) internal linkages – it is important for the logistics manager to control both internal supply functions and physical distribution and (iii) external linkages – logistics management requires cooperation in management with upstream and downstream entities in order to maximize the benefits of the total logistics system.

2.1.2 Definitions of SCM

Tsay *et al.*, 1998 defined a supply chain as two or more parties linked by a flow of goods, information and funds. Many definitions of the concept of supply chain (SC) have been provided in the literature. Mabert and Venkataraman (1998) discussed different views on supply chains i.e. (i) the "relational" activities between a buyer and seller, (ii) including all "upstream" suppliers, and (iii) a "value chain" approach, in which all activities required to bring a product to the market-place are considered part of the supply chain". Stevens defined a supply chain as a connected series of activities which is concerned with planning, coordinating and controlling materials, parts, and finished goods from supplier to customer. It is concerned with two distinct flows (material and information) through the organization" (Stevens, 1989). SCM has been defined in various ways (see table 2.1), many of which define the same issue in different words. Some commonalties can be distinguished and are given below:

- Embracing an integral perspective across the supply chain
- Enhancing customer responsiveness
- Adopting flow management of materials and information
- Optimal co-ordination and configuration of the supply chain process
- Minimizing the total system wide costs along the supply chain
- Rejection of intra- and inter-organizational boundaries
- Achieving partnership arrangements

Table 2.1: Definitions of supply chain management

Authors	Definition
Jones and Riley (1985)	SCM is an integrative approach to dealing with the total flow of materials from suppliers through end users.
Goldratt and Cox (1986)	SCM is defined as an enabler, a tool to achieve a company's goal.
Brown (1987)	SCM is a complex, dynamic network or system of interconnected and interdependent individuals, groups, companies, organizations, and relationships whose goal is to satisfy and add value to their particular customer.
Houlihan (1988)	SCM covers the flow of goods from supplier through manufacturer and distributor to end-user.
Ellram and Cooper (1990)	SCM is an integrative philosophy to manage the total flow of a distribution channel from the supplier to the ultimate user.
Ellram (1991)	SCM is defined as an integrative approach to dealing with the planning and control of the materials flow from suppliers to end-users.
Novack and Simco (1991)	SCM covers the flow of goods from the supplier through the manufacturer and distributor to the end user.
Scott and Westbrook (1991)	SCM is used to refer to the chain linking each element of the production and supply process from raw materials through to the end customer.
Lee and Billington (1992)	SCM is the networks of manufacturing and distribution sites that procure raw materials, transform them into intermediate and finished products, and distribute the finished products to customers.

Cooper and Ellram (1993)	SCM is an approach whereby the entire network from which suppliers through the ultimate customer, is analyzed and managed in order to achieve the "best" outcome for the whole system.
Davis (1993)	SCM is an approach (that) will enable a manufacturing operation to better manage its supply chain, ultimately improving customer satisfaction levels while reducing overall costs.
Lamming (1993)	SCM is a networking approach to value chain optimization.
Martha and Lisa (1993)	SCM is an integrating philosophy to manage the total flow of a distribution channel from supplier to the ultimate customer.
Turner (1993)	SCM is a technique that looks at all the links in the chain from raw material suppliers through various levels of manufacturing to warehousing and distribution to final customer.
Berry *et al.*(1994)	SCM aims at building trust, exchanging information on market needs, developing new products, and reducing the supplier base to a particular original equipment manufacturer (OEM) so as to release management resources for developing meaningful, long-term relationship.
Johannson (1994)	SCM requires all participants of the supply chain to be properly informed. With SCM, the linkage and information flows between various members of the supply chain are critical to overall performance.
Metz (1994)	SCM is defined as the coordination or integration of a series of activities/processes, which procure, produce, and deliver products or services to customers.
Lalonde and	SCM is the delivery of enhanced customer and economic value

James (1994)	through synchronized management of the flow of physical goods and associated information through sourcing to consumption.
Berry (1995)	SCM is a system whose constituent parts include material supplies, production facilities, distribution services and customer linked together by feed forward flow of materials and feedback flow of information.
Slack *et al.* (1995)	SCM is the concept of strategically coordinating supply chains.
Walton and Miller (1995)	SCM is the strategic integration of trading partners.
Giunipero and Brand (1996)	SCM is a strategic tool used to enhance overall customer satisfaction that is intended to improve a firm's competitiveness and profitability.
Johnson and Wood (1996)	SCM is a process of strategically managing the movement and storage of materials, parts, and finished inventory from suppliers through the firm and on to the customers.
Lamming (1996)	SCM is the extent of vision required on the part of managers with respect to their value-adding system, and the influence they must seek to have over it.
Thomas and Griffin (1996)	SCM is the management of material and information flows in and between facilities such as vendors, manufacturing and assembly plants and distribution centers.
Harland (1996)	SCM is defined as managing business activities and relationships (i) internally within an organization, (ii) with immediate suppliers, (iii) with first and second-tier suppliers and customers along the supply chain and (iv) with the entire supply chain.

Bechtel and Yayaram (1997)	SCM focuses attention on the interactions of channel members to produce an end product/service that will provide value for the end user.
Caldwell and Down (1997)	SCM is defined as managing value across organizational boundaries, which mandates new forms and new ways of managing inter-corporate relationships
Cooper *et al.* (1997)	SCM is the integration of all key business processes across the supply chain.
Cooke (1997)	SCM is the coordination and integration of all activities associated with moving goods from the raw materials to the end users, for sustainable competitive advantage. This includes systems management, sourcing, production scheduling, order processing, inventory management, transportation, warehousing, and customer service.
Kopczak (1997)	SCM is the set of entities including suppliers, logistics services providers, manufacturers, distributors and resellers, through which materials, products and information flow.
Lee and Ng (1997)	SCM is the network of entities that starts with the supplier's supplier and ends with the customer's customer involved in the production and delivery of goods and services.
Rich and Hines (1997)	SCM is centered on organizational restructuring and extends to the development of a company-wide collaborative culture but also embraces a strong sense of the integration of all activities, which control the timing, and synchronization of material flows.
Towill (1997)	SCM is an integrating process based on flawless delivery of basic

	and customized services.
Alber and William (1998)	SCM is used to deliver products and services from raw materials to end customers through engineered flow of information, physical distribution, and cash by global network.
Christopher (1998)	SCM is the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole.
Lambert *et al.* (1998)	SCM is the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders.
Mabert and Venkataramanan (1998)	SCM is the network of facilities and activities that performs functions of product development, procurement of material from vendors, the movement of materials between facilities, the manufacturing of products, the distribution of finished goods to customers, and after-market support for sustainment.
Ross (1998)	SCM is a continuously evolving management philosophy that seeks to unify the collective productive competencies and resources of business functions found both within the enterprise and outside in the firm's allied business partners located along interesting supply channels into a highly competitive, customer enriching supply system focused on developing innovative solutions and synchronizing the flow of market place, products, services and information to create unique, individualized sources of customer value.
Tan *et al.* (1998)	SCM encompasses materials/supply management from the supply

	of basic raw materials to final product (and possibly recycling and re-use). SCM focuses on how firms utilize their suppliers' processes, technology and capability to enhance competitive advantage. It is a management philosophy that extends traditional intra-enterprise activities by bringing trading partners together with the common goal of optimization and efficiency.
Tyndall *et al.* (1998)	SCM is the coordinated flow of materials and products across the enterprise and with trading partners. It is also includes the management of information flow, cash flow and process/work flow.
Hoek (1998)	SCM is characterized by control based on networking and integration of processes across functional, geographical, and organizational interfaces.
Akkermans *et al.* (1999)	SCM increases customer service and profitability through coordination/integration of multiple echelons, processes, and functions like suppliers, purchasing, manufacturing, distribution, marketing/sales, and customers.
Beamon (1999)	SCM is an integrated process where raw materials are transformed into final products then delivered to customers.
Hicks (1999)	SCM is systematic effort to provide integrated management to meet customer needs and expectation from the suppliers of raw materials through manufacturing to end-customers.
Ayers (2000)	SCM is more than the physical movement of goods from earth to earth. It is also information, money movement, and the creation and deployment of intellectual capital.

Ballou *et al.* (2000)	SCM involves all activities associated with the transformation and flow of goods and services, including their information flows, from sources of raw materials to end-users. For coordination to continue there is a need for metrics that can identify and capture chain wide benefits and costs, information sharing mechanism to distribute this data among chain members, and an allocation mechanism for redistributing the rewards of collaboration.
David *et al.* (2000)	SCM is a set of approaches to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements.
Hopp and Spearman (2000)	SCM is defined as the overall system wide coordination of inventory stocks and flows.
Chopra and Meindl (2001)	SCM involves the management of flows (i.e. information, product and funds) between and among the stages in supply chain to maximize total profitability.
Stanley and Gregory (2001)	SCM is the collaborative effort of multiple channel members to design, implement and manage seamless value added processes to meet the real needs of the end customer. The development and integration of people and technological resources as well as the coordinated management of materials, information, and financial flows underlie successful supply chain integration.
John (2001)	SCM is defined as the systematic, strategic coordination of the traditional business functions within a particular company and

	across businesses within the supply chain, for the purpose of improving the long-term performance of the individual companies and supply chain as whole.
Norina and Bailey (2001)	SCM is defined as an integration of each supply chain member's organizational activities in order to achieve particular objectives through achieving system-wide objectives.
Sheikh (2001)	SCM is defined as the planning, design, and control of the flow of information, materials, and money along the supply chain in order to meet customer requirements in an efficient manner, now and in the future.
Charles and Bauer (2002)	SCM refers to the methods, systems and leadership that continuously improve an organization's integrated processes for product and service design, sales forecasting, purchasing, inventory management, manufacturing or production, order management, logistics, distribution and customer satisfaction.
Michiel *et al.* (2002)	SCM is a systems approach to managing the entire flow of information, materials, and services from raw materials suppliers through factories and warehouses to the end customer.
Monczcka *et al.* (2002)	SCM is the integration of all activities associated with the flow and transformation of goods from the raw materials stage (extraction), through to end users, as well as the associated information flows through improved supply chain relationships to achieve a sustainable competitive advantage.
Gaither and Frazier (2002)	SCM involve all management functions related to the flow of materials from company's direct suppliers to its direct customers,

	including purchasing, warehousing, inspection, production, materials handling, and shipping and distribution.
Coyle *et al.* (2003)	SCM can be viewed as a pipeline or conduit for the efficient and effective flow of products/materials, services, information, and financials from the supplier's suppliers through the various intermediate organizations /companies out to the customer's customers or the system of connected logistics networks between original vendors and ultimate final customer.
Handfield and Nichols (2003)	SCM is the integration and management of supply chain organizations and activities through cooperative organizational relationships, effective business processes, and high levels of information sharing to create high-performing value systems that provide member organizations a sustainable competitive advantage.

2.1.3 Difference between physical distribution system, logistics management and SCM

The roots of SCM can be localized in logistics literature. The management consultants Oliver and Webber first mentioned the term in the early 1980's to shift attention to cross-functional integration (Ganeshan, Magazine and Paul, 1999). There are some irritations concerning the wording within and between Logistics Management (LM) and SCM. To avoid that in 1998, Council of Logistics Management (CLM) revised its definition, clearly subordinating logistics under the banner of SCM. It is defined as "Logistics is that part of the supply chain process that plans, implements and controls the efficient, effective flow and storage of goods, services and related information from the point of origin to point of consumption in order to meet customer's requirements". Logistics creates competitive advantage by flawlessly executing customer service objectives, achieving conformance to quality standards and increasing marketplace value. Perhaps the best way to understand logistics is to divide it into two separate, yet closely integrated functions. The first function is termed as materials management and is identified with incoming flow of information and material into the enterprise. The second function comprising logistics is physical distribution. The function is normally associated with the warehousing and movement of finished goods and service parts through the distribution channel to meet customer order fulfillment and delivery requirement. Supply chain management requires radical thinking that challenges traditional paradigms not only about logistics organizational structure and design but also about how channel partners are to be integrated, the level of participation of suppliers and customers in product and process design and logistics decisions, employee ownership and involvement and the use of information and communications technologies. Table 2.2 gives a clear cut idea of how Physical distribution system (PDS), Logistics management (LM) and SCM differ from each other.

Table 2.2: Difference between PDS, LM and SCM

Attributes/Sub-attributes	PDS	LM	SCM
1.Organization			
Management focus	Operational performance.	Logistic planning strategies or tactics.	Supply chain vision, objective and goals.
Vision	Fulfill demand at lowest cost.	Lowest cost. High quality.	High customer service. Innovation.

			High quality
Span	Less	More	Global
Integration	None	Importance of integrating operations within organization like sales, procurement, manufacturing, warehousing, distribution and transportation was recognized	High and critical Extend the scope of integration to link external partner like supplier, distributor, customer and vendor
Empowerment	Less.	More.	Maximum.
Industrial relations	Need lot of efforts to make good relations.	Need efforts to make good relations.	Built -in.
Team structure	Team from same department.	Cross functional team.	Cross functional team.
Organization structure	Tall hierarchy.	Less hierarchy system.	Flat management.
Organization design	Decentralized function.	Centralized function.	Developing partnership. Virtual organization.
Profit sharing	Profit for themselves.	Sharing with limited channels.	Sharing with all.
Return on investment	Less.	More.	Maximum.
Competitive advantage	Less.	More.	Maximum.
2.Process design			
Function	Warehousing. Transportation.	Warehousing. Transportation. Manufacturing. Procurement. Order management.	Supplier. Warehousing. Transportation. Manufacturing. Procurement.

			Order management
Automation	Less	More	Maximum
Dynamic trade	Not suitable	Not suitable	Maximum
Capacity utilization	Less	More	Maximum
Complexity	Less	More	Maximum
Flexibility	Less	More	Maximum
Information flow	Less	More	High and critical
Administrative efforts	More.	Less.	Least.
Decision focus	Operational activities.	Operational and tactical activities.	Simultaneously on strategic, tactical and operational activities.
Forecasting	Difficult.	Difficult.	Easy to manage as supply chain and is designed to sense early warning signals.
Response time	More.	Less.	Least.
Uncertainties	Difficult to incorporate.	Difficult to incorporate.	Easy to incorporate as information flow is quick and high.
Tracing and expediting	Difficult.	Difficult.	Easy.
Security requirements	Less.	More.	Maximum.
3. Purchasing			
Supplier selection	Short term contract.	Long term contract.	Long term contract.
Option available	Less.	More.	Globally available.
Supplier-buyer proximity	Few deliveries.	More deliveries.	Frequent deliveries.
Buyer-supplier co-operation	Competitive perspective	Profitable for both but self concern is more.	Win- win situation

Supplier evaluation	Price	Quality Delivery Price	In additional to quality, delivery and price, it has ability to manage product, information and financial flow for meeting competitive needs
4 Service management			
Lead time	More.	Less	Least.
Delivery reliability	Less.	More	Maximum.
Customer service level	Low.	Medium.	High.
Quality	It cost money to make quality.	Quality can be controlled.	Inherent.
Customer satisfaction	Less.	More.	Maximum.
5.Inventory system			
Work-in-progress	More.	Less.	Least.
Lot size	Large.	Optimum lot size.	Keep reducing lot size.
Inventory planning	Inventory is an asset and it protects against forecast error, m/c breakdown and late deliveries.	Control policies are used for planning inventory.	Inventory is an evil and every effort must be extended to minimize inventory.
6. Work force			
Multifunctional workers	Specialized and rigid.	Less flexible.	Flexible.
Motivation	Less [easy pace].	More.	High [hard pace].
Willingness to change	Resistance to change.	Less resistance.	Willingness to learn.
Training and education	Optimal training to meet immediate job requirement.	Training with focused view.	Life time training.

Skill	Narrow	Medium	Broad
Continuous improvement	No	Not much emphasis	Essential to survive
Risk and reward structure	No risk Sharing	Risk is shared only between key members	Risk is shared along the supply chain.
7 Miscellaneous			
Performance measurement	Firm focus performance measurement	Partially integrated performance measurement	Integrated supply chain performance measurement.
Product development	Independent.	Limited involvement.	Joint involvement.
Planning and control	Independent.	Planning with limited channels.	Joint planning between key members.

2.1.4 Supply chain management antecedents

Mentzer *et al.*, 2001 defined supply chain orientation (SCO) as "the recognition by a company of the systemic, strategic implications of the activities and processes involved in managing the various flows in a supply chain". He also identified eight antecedents to SCM (i.e. trust, commitment, interdependence, organizational compatibility, vision, key processes, leader, and top management support.). The first two, trust and commitment are widely recognized as necessary preconditions to any successful long-term relationship (Morgan and Hunt, 1994). The third antecedent identified by Mentzer *et al.*, 2001 is interdependence. Companies that do not recognize some level of dependence on other companies in their supply chain have little motivation to work with those companies. The next two antecedents are organizational compatibility and vision. The overriding theme is that firms in a supply chain should have similar operating philosophies and corporate cultures and visions (Cooper *et al.*, 1997), as well as decision-making style (Spekman et. al., 2001). A shared vision among all member firms of a supply chain provides each firm with the directions, objectives and strategies in how to manage the supply chain (Mentzer *et al.*, 2001). To work together successfully, the member firms must have similar operating philosophies and corporate cultures. The sixth antecedent is identifying key processes. Member firms should agree on the key processes of the supply chain (Lambert *et al.*, 1998) from which to begin to integrate. The identification of the key processes is what is crucial as those key processes become successfully managed at a supply chain level, and then other processes can be included. As with any initiative, SCM requires a supply chain leader (Mentzer *et al.*, 2001; Ellram and Cooper, 1990). One firm will play the key role in coordinating and overseeing the entire supply chain. Several factors may determine the supply chain leader, for example, size or economic power (Bowersox and Closs, 1996). Top management support is necessary and vital to sustain any long-term initiative and is the last antecedent. Resources originate from top management. Lack of support translates into lack of resources, which result in a failed initiative.

2.1.5 Performance measures of SCM

In the SCM, organizations must work together to help each other. Each node in the supply chain is a strategic link. Strong links make strong supply chains; weak link hurt every member in the chain. According to Cox (1999), "Companies are instructed to construct ever efficient and responsive supply chains because it will no longer be company with company, but supply chain competing against supply chain". Therefore one cannot simply focus on his or her company's performance; there is an emerging requirement to focus on the performance of the extended supply chain or network in which company is a partner. To maintain and encourage supply chain improvement, there is a need to go beyond the traditional functional and business performance measures and develop new metrics with enough detail and richness to handle the supply chain performance rather than individual business performance. Supply chain do many functions in an organization, therefore, it is critical that performance measures are not narrowly defined. One-dimensional metrics such as capacity utilization, inventory turns or costs will tend to give a distorted picture of the supply chain. Likewise, it is also seen that some companies achieved great improvements in their operational performance, but they did not impact on the end consumers due to overall poor performance in the supply chain. In the early eighties, it happened with General Motor, therefore, a supply chain is only as good as its weakest link (Hausman, 2000). Performance measures provide the means by which the achievement of the organizational goals and objectives are assessed in quantifiable terms (Carmen and Conrad, 2000). In theory and practice we often find the quotation that "you can not manage what you do not measure". But even measuring the operations need not necessarily lead to good results. Managers and employees are warned that "you get what you measure" or "be careful what you measure you might get it" (Lapide, 2000). Sahay *et al.* (2001) pointed out "each department measures supply chain performance in its own terms. Its members are evaluated on their ability to meet objectives consistent with departmental goals. Not surprisingly, then, they drive operations towards improving performance in their own department, often at the expense of other functional areas. When each sets its performance measures in isolation from other, narrow functional interests often conflict with broader supply chain goals". Traditionally, performance measurement is defined as the process of quantifying effectiveness and efficiency of action (Neely *et al.*, 1995). In modern business management, performance measurement goes well beyond just quantification and accounting. It is supposed to contribute much more to business management and performance improvement in the industries. From the management perspective, performance measurement provides necessary information of management feedback for decision makers and process managers. It plays the critical roles of monitoring performance, enhancing motivation and communication, and diagnosing problems (Rolstandas, 1999; Waggoner *et al.* 1999). Furthermore, performance measurement provides an approach for identifying success and potentials of management strategies, and facilitating understanding of progress and position. With these, it assists in directing management attention, revising company goals, and re-engineering business processes (Hoek, 1998; Bourn *et al.* 2000; Kuwaiti and Kay, 2000). Henceforth, accurate performance measurement is greatly helpful for improvement of SCM. Beamon (1999) identified three types of measures: resources, output, and flexibility. Supply chain models have predominately utilized two different performance measures: cost and a combination of cost and customer responsiveness. Costs may include inventory costs and operating costs. Customer responsiveness measures include lead-time, stock out probability, and fill rate. Table 2.3 summarizes the supply chain models available in the literature and the corresponding performance measures used. These models use the listed performance measures as objectives that are either minimized or maximized, subject to various operational constraints. Supply chain performance measures are classified into three categories i.e. time dependent performance measures, quantity dependent performance measures and quality dependent performance measures.

Table 2.3: Performance measures in supply chain modeling (Beamon, 1998)

Performance measures	Author(s)
Cost	Cohen and Lee (1988); Cohen and Lee (1989); Cohen and Moon (1990); Pyke and Cohen (1994); Tzafestas and Kapsiotis (1994); Lee and Feitzinger (1995)
Cost and activity time	Arntzen, Brown, Harrison and Trafton (1995)
Cost and customer responsiveness	Altoik and Ranjan (1995); Christy and Grout (1994); Cook and Rogowski (1996); Davis (1993); Ishii *et al.* (1988); Newhart *et al.* (1993); Towill (1997); Towill *et al.* (1992); Wikner *et al.* (1991)
Customer responsiveness	Lee and Billington (1996)
Flexibility	Voudouris (1996)

2.1.5.1 Time dependent performance measures

Time dependent performance measures are evaluated with respect to time. The time dependent performance measures are given below:

- Order fulfillment cycle time: The average actual lead times consistently achieved, in calendar days, from customer order to customer delivery.
- Customer inquiry resolution time: The average time required to completely resolve a customer inquiry.
- Customer inquiry response time: The average elapsed time between receipt of the customer call and connection with appropriate company representative.

- Supply chain response time: The number of days required to recognize a major shift in market demand.
- Cash to cash or cash conversion cycle time: It measures the time elapsed between paying suppliers for material and getting paid by customers.
- Supply chain cycle time (source/make cycle time): This parameter measures the total time it would take to fulfill an order if all upstream and downstream inventory levels were zero. It is measured by adding up the longest (bottle neck) lead times at each stage in the supply chain.
- Supply chain inventory days: Total number of days of inventory required to support the supply chain from raw materials to final customer acquisition.
- Vendor lead-time for basic order: It measures time from the receipt of goods assuming that entire order must be received. The measure applies to typical orders placed on regular basis.
- Vendor lead time for special orders: It measures time from the receipt of a purchase order until the receipt of goods assuming that entire order must be received. The measure applies to special orders placed infrequently, such as sales and promotions.
- New product introduction time: Most of the firms now employ multifunctional teams, composed of design engineers, marketing personnel, manufacturing mangers and production line workers. These firms have the procedures and organizational structure that facilitates

new product introduction. New product introduction time is the time between the introductions of new innovative products.

2.1.5.2 Quantity dependent performance measures

Quantity dependent performance measures are those measures for which there is single direct numerical measurement. The quantity dependent performance measures are given below:

- Item fill rate or product fill rate: It is the fraction of product demand that is satisfied from product in inventory. It is equivalent to the probability that product demand is supplied from available inventory.
- Order fill rate: It is the fraction of orders that are filled from available inventory. In a multi product scenario, an order is filled from inventory if all products in the order can be supplied from the available inventory.
- Cycle service level: It is the fraction of replenishment cycles that end with all the customer demand being met. A replenishment cycle is the interval between two successive replenishment deliveries. The cycle service level is equal to the probability of not having stock out in a replenishment cycle.
- Perfect order fill rate: A perfect order is an order that delivered complete, on time, in perfect condition and with accurate and complete documentation. Perfect order fill rate is the percent of orders that are perfect (perfect orders/total orders).
- Dollar fill rate: It measures the percentage of dollars received on a purchase order (PO) relative to the dollars ordered for the entire PO. It is measured based on dollar value of units received.
- Stock out rate: It is the complement of fill rate and represents the fraction of orders lost due to a stock out.

- Average number of late orders: It is the average number of orders waiting to be filled for a particular period of time.
- Average value of late orders: It is the average value of the back order waiting to be filled for a particular period of time.
- Asset Utilization: Asset utilization can be estimated by several different metrics such as net asset turns (i.e. a ratio of total gross revenue to working capital), inventory turns (a ratio of annual cost of goods sold to average inventory investment) and cube utilization (a ratio of space occupied to space available).
- Total supply chain cost: It includes total supply chain expenses (see table 2. 4).

Table 2.4: Total supply chain cost (Bowersox and Closs, 1996)

Order fulfillment costs	Material acquisition costs (production materials only)	Total inventory carrying costs	Logistic-related finance and management information system costs	Manufacturing labor and inventory overhead costs
New product release and maintenance. Customer order creation. Order entry and maintenance. Contract /program management. Installation planning. Order fulfillment. Distribution. Installation. Customer accounting.	Commodity management and planning. Supplier quality engineering. Inbound freight and duties. Receiving. Incoming inspection. Component engineering. Tooling.	Cost of capital/ opportunity. Shrinkage. Insurance and taxes. Obsolescence.	Finance. MIS/systems. Supply chain support costs.	Direct labor. Indirect labor. Manufacturing and quality engineering. Information systems. Scrap and rework. Depreciation. Lease expense. Plant occupancy. Equipment maintenance. External support. Environmental.

2.1.5.3 Quality dependent performance measures

Quality dependent performance measures are those measures for which there is no single direct numerical measurement, although some aspects of them may be quantified. The quality dependent performance measures are given below:

- Installation, warranty, repairs and service parts: These elements should be an important consideration in almost all purchases, especially purchases of capital equipment where such costs tend to far outweigh the cost of the purchased item itself. It is also important for high tech products (Lambert *et al.*, 1998).
- Customer complaints, claims and returns: To resolve customer complaints, an accurate on-line information system is needed to process the data from the customer, monitor trends, and provide the customer with the most current information available. Logistics systems are designed to move products to customers, so the cost of non-routine handling, particularly of small products such as customer returns tends to high. Corporate policies should be established to handle these complaints as efficiently and effectively as possible (Lambert *et al.*, 1998).
- Product tracking: Product tracking, also referred to, as product tracing, is an important customer service element. For example, in order to inform customer of potential problems, firms must be able to recall potentially dangerous products from the market once the potential hazard has been identified (Lambert *et al.*, 1998).

- Order and product flexibility: It is the ability to respond efficiently to demand flexibility (i.e. operator flexibility, machine flexibility, process flexibility).
- Effective risk management: All the relationships within the supply chain contain inherent risk. Effective risk management describes the degree to which the effect of these risks is minimized (Johnson and Davis, 1995).
- Supplier performance: With what consistency suppliers deliver raw materials to production facilities on time and in good condition.
- Social criteria: It includes employee turnover, work injuries and absenteeism.
- Function duplication minimization: Minimize the number of the business functions that are provided by more than one business entity (Nicoll, 1994).

2.1.6 Classification of SCM

One of the criteria, which cannot be ignored while comparing two supply chains, is that they should have the same demand response strategy. This in general refers to the strategy adopted by a company concerning the sequence of work processes taking place in the supply chain triggered by a customer order and which have to be completed efficiently in order to satisfy the customer and achieve profitability. Fisher (1997) recommended first examining a product's demand nature in order to determine what type of supply chain to use. Generally the following demand response strategies are employed in SCM.

Make-to-Stock (MTS): Here the end customer orders are filled from stocks of inventory of finished goods that are kept in the supply chain network's (SCN) various retail points.

Assemble-to-Order (ATO): This strategy involves having the same core assemblies for most products and the ability to vary all other components of the final assembly based on customer preference.

Make/Engineer-to-Order (M/ETO): In this strategy it is the confirmed customer order that triggers the flow of materials and information in the supply chain. Hence there is very little or no inventory maintained of the finished goods. In MTO, designs are the only items held in inventory while in ETO the design is also developed only after receiving the customer order. A comparison of these demand response strategies based on several attributes is made (see table 2. 5). The supply chains are classified into three types (MTS, ATO and M/ETO supply chain) according to their demand response strategies.

Table 2.5: Comparison of MTS, ATO and MTO/ETO environments (Wemmerlov, 1984 and Sari, 1997)

Aspect	Make to stock (MTS)	Assembled to order (ATO)	Make/Engineer to order (M/ETO)
Interface between manufacturer and customer	Low/Distant	Primarily at sales level	Engineering and sales level
Delivery time	Short	Medium	Long
Production volume of each sales unit	High	Medium	Low
Product Range	Low	Medium/ high	High
Basis of production, planning and control	Forecasts of each sales unit (end item)	Option forecasts for master scheduling, and backlog for final assembly scheduling	Backlog and customer intelligence forecasts
Order promising	Availability of	Availability of standard	Availability of

	finished goods inventory	modules and common parts	manufacturing and engineering capacity
Handling of demand uncertainty	Safety stocks of sales units	Over planning of standard modules and common parts	Little uncertainty exists about materials. For uncertainty in capacity requirements, excess capacity is usually planned
Master scheduling unit	End items/Sales units	Standard modules–Variants, Add-ons, Attachments, Accessories, Intermediaries and common parts	Customer orders; Management authorizations of long lead time components and speculative items; Standard raw materials and components
Items held in inventory	Finished products (very high inventory carrying costs)	Major modules/ sub-assemblies, Common parts (Lower inventory carrying costs for the total variety)	Product designs and standard raw materials (lowest inventory carrying costs)
Final assembly scheduling	Close correspondence to the master schedule.	Determined by customer orders received by order entry.	Covers most of the assembly operations
Bill of material structuring	Standard BOMs for each sales item	Planning BOMs	Unique BOMs for each order
Critical/ important MRPII/ERP modules	Distribution Resource Planning	Product Configurator, MPS, MRP I and FAS	FAS, CRP, SFC

2.1.7. Performance metrics for different SCM

The performance of each SCM should be measured with the help of specific performance metrics. This enables to benchmark the SCM by comparing it with the best in the business. Thus the effectiveness of the supply chain can constantly be improved the metrics that are used to measure the supply chain performance are different for different supply chains. MTS supply chains based on demand forecasts, and try to limit risk by limiting the product range. MTO supply chains are prepared to provide much-customized products, but start to produce only after receipt of customer order. ATO supply chains position themselves in between MTS and MTO, and address primarily the markets of durable products. With an ATO supply chains divide the value chain into two stages minimizes customer order lead times i.e. a stage of module manufacture based on forecasts followed by a stage of final assembly of customized products. Risk is minimized by modularizing products and by standardizing modules as much as possible. MTS, MTO and ATO supply chains differ essentially by a different position of the decoupling point. A decoupling point is defined as a physical point in the value chain of the production system, which separates the investment stage from the realization stage. Within the investment stage, operations are executed in response to firm and anticipated demand. Within the realization stage, production is against firm customer orders. The decoupling point determines the minimum order lead-time. A decoupling point must correspond with stocks somewhere in the supply chain, as the result of the fact that forecasts never are perfect. The position of the decoupling point determines the type of supply chain that the company has to adopt. A list of dominant performance metrics for MTS, MTO and ATO supply chains is given in the table 2. 6.

Table 2.6: Performance metrics for different supply chains

	MTS supply chain	MTO supply chain	ATO supply chain
Time dependent performance measures	Supply chain cycle time. Cash conversion cycle time. New product introduction time. Vendor lead-time for basic order. Supply chain inventory days.	Order fulfillment cycle time. Supply chain response time. Customer inquiry response time. Customer inquiry resolution time. Vendor lead-time for basic order.	Customer inquiry resolution time. Order fulfillment cycle time. Customer inquiry response time. Cash to conversion cycle time. Vendor lead time for special orders. New product introduction time.
Quantity dependent performance measures	Total supply chain cost. Product fill rate. Order fill rate. Average value of late orders. Asset utilization.	Perfect order fill rate. Dollar fill rate. Asset utilization. Total supply chain cost.	Product fill rate. Cycle service level. Perfect order fill rate. Dollar fill rate. Average number of late orders. Average value of late orders.
Quality dependent performance measures	Customer complaints, claims and returns. Supplier performance. Effective risk management. Product tracking. Social criteria.	Installation, warranty, repairs and service parts. Customer complaints, claims and returns. Supplier performance. Order and product flexibility.	Installation, warranty, repairs and service parts. Customer complaints, claims and returns. Product tracking. Order and product flexibility. Supplier performance. Effective risk management.

2.2 Literature review

Considering a broad spectrum of the supply chain concept, there may be various classification schemes to categorize supply chain models. The taxonomy of supply chain based on mathematical models can be classified as: deterministic and stochastic (Beamon, 1998; Bradley *et al.*, 1977; Budnick *et al.*, 1988; Mentzer and Schuster, 1983). As noted by Budnick *et al.* (1988), Silver (1981) and Zipkin (2000), some supply chain models based on inventory theory and simulation contain both deterministic and stochastic elements and consequently should be treated as hybrids. Therefore, a hybrid model to the category is added. Another category called 'IT-driven models' was added to the taxonomy to reflect the current advances in IT for improving supply chain efficiency. These categories are somewhat different from the taxonomy developed by Beamon (1998) who did not report the evolution of IT-driven models. To elaborate, the supply chain models are classified into four major categories: (1) deterministic (non-probabilistic); (2) stochastic (probabilistic); (3) hybrid; (4) IT-driven. Deterministic models assume that all the model parameters are known and fixed with certainty, whereas stochastic models take into account the uncertain and random parameters. Deterministic models are dichotomized as single objective and multiple objective models. This category was developed to reflect the increasing need to harmonize conflicting objectives of different supply chain partners. Stochastic models are sub-classified into optimal control theoretic and dynamic programming models. The categories of decision analysis and queuing models are excluded from stochastic models, because the literature indicates that supply chain models rarely used such techniques. Hybrid models have elements of both deterministic and stochastic models. These models include inventory-theoretic and simulation models that are capable of dealing with both certainty and uncertainty involving model parameters.

Shapiro (2001) recently observed that IT development was the major driving force for supply chain innovations and the subsequent re-engineering of the business process. Considering the proliferation of IT applications for supply chain modelling, the category of IT-driven models is added to the taxonomy. IT-driven models aim to integrate and coordinate various phases of supply chain planning on real-time basis using application software so that they can enhance visibility throughout the supply chain. These models include warehouse management system (WMS), transportation management systems (TMS), integrated transportation tracking, collaborative planning and forecasting replenishment (CPFR), material requirement planning (MRP), distributive resource planning (DRP), enterprise resource planning (ERP), and geographic information systems (GIS). Some of these models, such as WMS, CPFR, ERP and GIS, are gaining popularity due to their significant roles in facilitating information flow across the supply chain.

A WMS generally refers to a series of computer software and hardware that integrate bar coding, radio frequency communication, cycle counting, and other warehouse-related operations to accelerate the flow of material and utilize space throughput the warehouse. WMS ultimately aims at reducing the stock in the supply chain, ensuring shorter lead times, and improving customer satisfaction. WMS can track and control the movement of inventory through the warehouse from receiving to shipping. WMS can track and control the movement of inventory through the warehouse from receiving to shipping. WMS also gives users a current and accurate picture of the quantity, location, and age of inventory. Hence, without an effective WMS, the optimization of warehousing operations within the supply chain is nearly impossible. This optimization can be achieved by utilizing a WMS that enables the user to conduct any number of varying physical operations such as put ways, cross-docking, and cycle counting on a real-time basis (Alex, 2000).

CPFR is designed to link consumer demand with supply chain planning and execution by promoting a single, jointly owned demand plan and forecast throughout the entire supply chain (Ireland and Bruce, 2000). ERP employs multi-module software for managing and controlling a broad set of supply chain activities including product planning, parts purchasing, inventory control, order tracking, a human resource planning (Swamidass, 2000). In other words, ERP acts as the central nervous system of an organization that manages every transaction involving the acquisition, movement, and storage of goods throughout the organization. The main intent of ERP is to increase the velocity of inventory throughout the supply chain. Along with WMS and CPFR, ERP is an important pre-requisite for successful collaboration among supply chain partners.

GIS simplifies the data display mechanism by separating data presentation from data storage and then allowing the model builder to visualize how distinctive one geographic site is from another by superimposing geographic information, such as population density, racial makeup, and temperature on a map. Combined with some database management system (DBMS), GIS may provide a friendly platform for the enhancement of dialogue among supply chain partners. Figure 2.1 shows the taxonomy of supply chain modelling. In addition to the taxonomy developed earlier based on the mathematical structure, supply chain models can also be classified into various frameworks with respect to their problem scope or application areas. The problem scope is viewed as a criterion for measuring the realistic dimensions of the model. Considering the inherent nature of supply chain problems that cut across functional boundaries, supply chain models involve making tradeoffs between more than one business process (function) within the supply chain. Therefore, only the models that attempt to integrate different functions of the supply chain are regarded as supply chain models. Such models deal with the multi-functional problems of location/routing, production/distribution, location/inventory control, inventory control/transportation, and supplier selection/inventory control (Figure 2.2). Interested readers may refer to Weber *et al.* (1990) for a review of supplier selection problems, Min, Jayaraman, and Srisvastava (1998) for a review of location/routing models, and Erenguc *et al.*, 1999 for a review of production/distribution planning. Some of these models are hierarchical in that they consider various phases (echelons) of supply chain planning. Given the great availability of past studies on integrated modelling efforts, review will focus primarily on studies that have been published since 1998 and can be viewed as important theoretical foundations for the evolution of analytical supply chain models. These theoretical foundations include new algorithmic developments and/or new mathematical formulations for supply chain problems. Also past supply chain modelling efforts that are omitted by Beamon (1998), Ganeshan *et al.* (1999), Slats *et al.* (1995) and Thomas and Griffin (1996) are included.

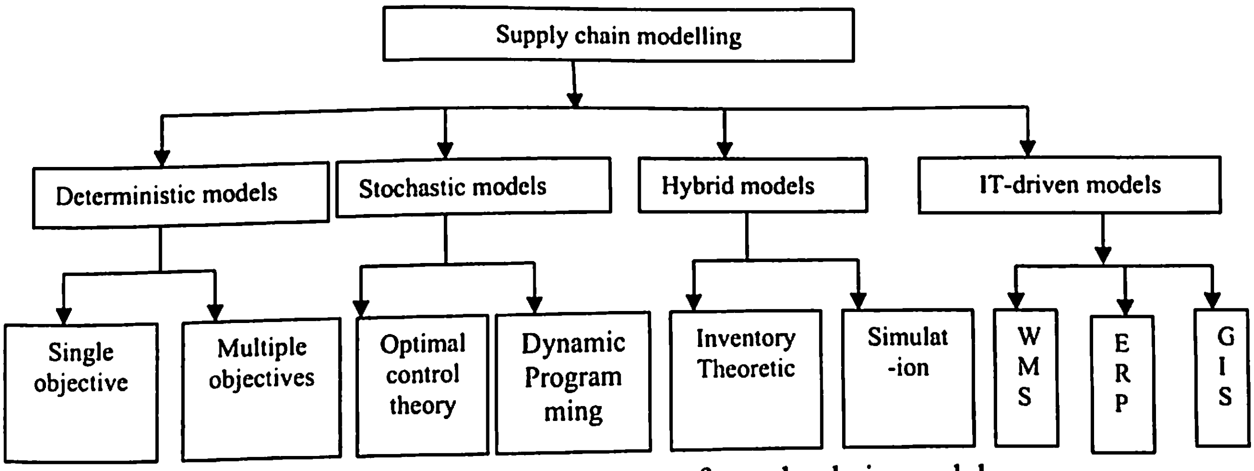

Figure 2.1: Taxonomy of supply chain models

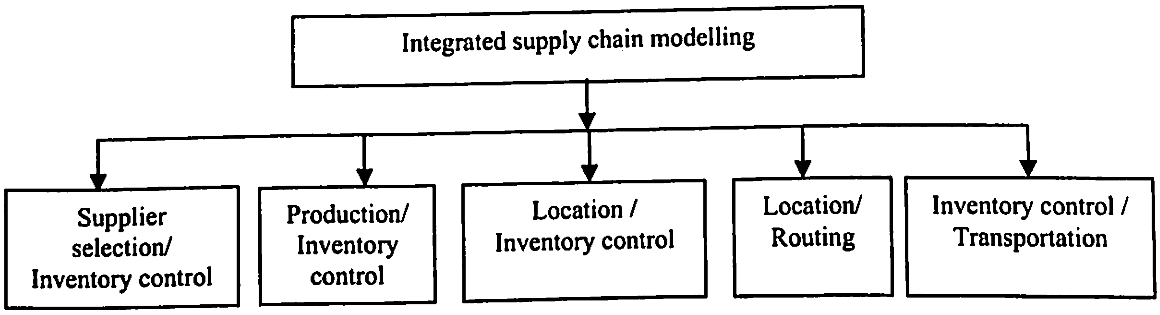

Figure 2.2: Types of integrated supply chain models

2.2.1 Deterministic models

One of the earliest efforts to create an integrated supply chain models dates back to Geoffrion and Graves (1974) and Glover *et al.* (1979). Geoffrion and Graves (1974) introduced a multi-commodity, logistics network design model for optimizing finished product flows from plants, to the distribution centers to the final customers. Glover *et al.* (1979) developed a computer-based production, distribution, and inventory (PDI) planning system that integrated three supply chain segments comprised of supply, storage / location, and customer demand planning. The core of the PDI system was a network model and diagram that increased the decision maker's insights into supply chain connectivity. The model however was confined to a single-period and single-objective problem. Geoffrion and Powers (1995) gave a review of evolution of distribution strategies over the past twenty years, describing how the descendants of the above model can accommodate more echelons and cross commodity detail.

The international plant location problem model presented by Hodder and Dincer (1986) is a large scale non-linear MIP, and it is very difficult to solve. The model is nonlinear due to the inclusion of the financial variables to allocate the costs to plants. By developing an approximation procedure, the authors transform the model into a more tractable, but still nonlinear, formulation. Cohen and Lee (1989) developed a mixed-integer non-linear, value-added chain model that coordinated the supply chain process comprised of sourcing, centralized production planning, and inter-plant transhipment. The model incorporated capacity, demand, and production constraints, but failed to capture risk factors inherent in a global setting. Cohen and Moon (1991) presented a mixed integer, multi-commodity model to find inbound raw material flows, assignment of product lines and specification of production volumes and outbound finished product flows in a production distribution network. The model contains binary variables for assigning products to plants and for determining the part of the concave curve of production costs to be applied. Research results show that global optimal solutions are frequently difficult to obtain unless a special structure exists. A variant of the generalized Benders decompositions technique is applied.

Arntzen *et al.* (1995) presented a mixed-integer programming model, called global supply chain model (GSCM) which evaluated global supply chain alternatives involving multiple products and multiple stages (echelons). More specifically, GSCM took into account the interdependence of production, inventory and delivery processes to minimize activity days and costs associated with production, inventory, material handling, and transportation.

Ashayeri and Rongen (1997) refined a grid model and the multi-criteria solution method called ELECTRE to formulate the distribution centre (DC) repositioning strategy based upon the analyses of material flows, DC locations, and throughput times. Although the proposed model and solution method were simple to use, they were confined to single-period and un-capacitated problems. Another multiple objective approach was proposed by Min and Melachrinoudis (1999) to configure multi-echelon supply chain networks connecting material flows among suppliers, manufacturers, break-bulk terminals, and customers. Their analytic hierarchy process-based model also considers contingency planning associated with supply chain reconfiguration. It, however, did not consider multiple periods, capacity constraints and risk factors.

More recently, Melachrinoudis and Min (2000) extended their previous work by designing a multi-objective, multi-period mixed integer programming model that determined the optimal relocation site and phase-out schedule of a combined manufacturing and distribution facility from supply chain perspectives. A similar problem was solved by Melachrinoudis *et al.* (2000) using a novel methodology called physical programming which allows a decision maker to express multi-criteria preferences not in the traditional form of weights but in terms of range of different degrees of desirability. In addition to the selection of the new site, the model determines the optimal schedule for relocating capacity from the existing site to the new site, the production levels in the two sites during the transitional period, and the shipments to the customers in each period of the multi-period planning and horizon.

In an effort to integrate inventory, transportation, and location functions of a supply chain, Nozick and Turnquist (2001) proposed an approximate inventory cost function and then embedded it into a fixed-charge location model. The fixed-charge facility location model was designed to consider a tradeoff between demand coverage and cost associated with the location of automobile DCs. Although the model deals with multiple objective (service-cost trade-off) issues, it is confined to a single period, single echelon problem with no capacity constraint.

2.2.2 Stochastic models

In an increasingly competitive environment, there are many uncertain or random elements in the supply chain such as customer demands, lead times, and production fluctuation. The stochastic models take into account these uncertain and random elements. One of the pioneering works dealing with the stochastic nature of the integrated supply chain is credited to Milder (1969), who developed a dynamic programming model based on optimal control theory for selecting an optimal combination of transportation modes, commodity flows, and re-routing of carriers from customers and suppliers over a multi-period planning horizon.

Tapiero and Solilman (1972) utilized optimal control theory to solve multi-commodity transportation, multi-regional production and inventory planning problems over time with uncertain demand. Despite its merit, the model combining linear and parametric programs created severe computational difficulty.

Lee and Billington (1996) attempted to integrate the material flow of marketing, manufacturing, and material ordering policy, the customer service level for each product, and postponement strategies. Similarly Lee and Feitzinger (1995) and Swaminathan and Tayur (1999) presented stochastic models to formulate postponement (delayed product differentiation) strategies. In particular, Swaminathan and Tayur (1999) provided stochastic programming models and effective computational procedures to study inventories of common components, the use of vanilla boxes for postponement and the effect of assembly task sequencing on operational performance. They also utilized the inherent structure of problems to develop computationally efficient algorithms based on sub-gradient methods. In robust optimization, the uncertainty about the problem data is treated as deterministic, unknown but bounded (e.g. via intervals of confidence for the data). A robust solution is one that tolerates changes in the problem data up to a given bound known as a priori. Ahmed and Salinities (1998) developed a robust optimization framework for the problem of supply chain planning in the process industries. Since the standard stochastic programming formulation of the problem does not address the variability of the uncertain recourse costs across the uncertain parameter scenarios, they extended the stochastic programming formulation to account for robustness of the recourse costs through the use of an appropriate variability criterion. To overcome the difficulty associated with solving the robust models that include non-separable terms, they developed a heuristic procedure for the restricted recourse formulation. This method iteratively enforces recourse robustness while solving the standard stochastic program in each step. Their models can provide the decision maker with a tool to analyze the trade off associated with the expected profit and its variability.

In the meantime, several attempts have been to quantify the effects of imbalance between supply and demand in the supply chain. These attempts include Fisher *et al.* (1997) who developed a stochastic program that aimed to minimize under production and overproduction costs as a result of imbalance between supply and uncertain demand in the supply chain. Similarly, Lee *et al.*, (1997) investigated the bullwhip effect that might arise when order variances distorted customer demand and consequently created imbalance between supply and demand in the supply chain. Metters (1997) followed up on Lee *et al.*, (1997) by developing a dynamic programming model that aimed to minimize the expected costs of production, inventory holding, and excess demand penalty, subject to production obeying capacity constraints.

2.2.3 Hybrid models

The single highest cost in a supply chain is inventory which accounts for nearly half of the total logistics costs (Lancioni, 2000). Due to the heavy influence of inventory on the supply chain cost, the literature dealing with inventory theoretic models is relatively rich. Baumol and Vinod (1970) are credited with the introduction of one of the most classic inventory theoretic models. Although they did not differentiate between truckload (TL) and less-than-truckload (LTL) freight rates, their model allowed a decision maker to make tradeoffs among direct shipping cost, in-transit carrying cost, ordering cost and a consignee's inventory carrying cost. Since in-transit carrying cost is a surrogate measure of transit time (speed of delivery), their model can be used for analysing tradeoffs between cost (inventory level) and time (transit time).

Das (1974) modified the inventory theoretic model proposed by Baumol and Vinod (1970) by considering a more general estimate of the demand variability. His model can also be applied to inter-modal solutions. Karmarkar and Patel (1977) used a decomposition approach to solve a single product, single period, multiple location inventory problem with stochastic demands and transhipment between locations. To consider interactions between inventory management and transportation modal choice, Constable and Whybark (1978) further extended the inventory theoretic model. They added expected backorder cost to the original inventory theoretic model suggested by Baumol and Vinod (1970).

Herron (1983) employed the inventory theoretic model to not only relate the level of customer service to the inventory level, but to also determine the frequency of expedite shipment in case of stock-outs. Blumenfeld *et al.* (1985) developed a model similar to Herron (1983) to make a trade-off between freight expedition and safety stock holding cost. Some variants of the inventory theoretic model were used on a location-inventory problem where demand is uncertain and re- distribution of inventories is permissible between order cycles (Das, 1975). Schwarz (1981) developed an inventory theoretic model based on Clark and Scarf (1960) to determine the size of the total inventory investment and the location of inventory stocking points simultaneously. Their model, however, is limited to a single commodity problem. Another shortcoming of the model is severe computational complexity that may prohibit its application to a real-world problem. Singh and Vrat (1984) developed a more practical model that was designed to determine the optimal location of repair part stocking pints and the allocation of repair part inventory to that location.

Despite the popularity of the inventory theoretic models in the supply chain modelling literature, some alternative models proposed by Bookbinder, McAuley, and Schulte (1989), Cachon (1999), Karabakal *et al.* (2000) and Newhart *et al.* (1993). To elaborate, Bookbinder *et al.*, (1989) employed both spreadsheet-based simulation and linear programming models to evaluate inventory / production alternatives and then select the best alternative, while making a tradeoff between transportation cost and inventory investment. However, like past studies reviewed earlier, Bookbinder *et al.*, 1989 did not estimate the impact of backhauls on transportation cost. Newhart *et al.*, 1993 used both spread sheet-based inventory and mathematical programming models to determine the most cost efficient methods of production and inventory with consolidation.

More recently, Cachon (1999) utilized a game theory to take into account an infinite horizon, stochastic demand inventory problem between one supplier and one retailer. In this game theory, Cachon (1999) considered the possibility of 'double marginalization', buy-back contracts and quantity discounts to develop the optimal joint inventory policy. Karabakal *et al.*, 2000 used a combination of simulation and mixed-integer programming models to determine the number and location of automobile distribution and processing centers as well as set of market areas covered buy by each distribution and processing centre, while evaluating customer performance measures, such as ability of the supply chains to deliver a customer's preferred vehicles within short time windows.

Given that a simulation model is well-suited for evaluating dynamic decision rules under 'what if scenarios', a few attempts have been made to develop simulation models to improve supply chain dynamics involving demand amplification with the presence of many supply chain players. These include Towil *et al.* (1992) and Winker, Towil and Naim (1991). The main purpose of both studies is to create best decision rule that will allow decision maker to reduce lead times, compress the distribution channel and coordinate information flow throughout the supply chain. One of the most intriguing features of their models is the use of influence diagrams that visualise the cause-and-effect relationship between the decision rule and the improvement in the supply chain performances. As suggested by Swaminathan *et al.*, (1998), reengineering the supply chain because of business dynamics is becoming a necessity, but it is not an easy task. Although software simulation tools can ease the burden of analysis, it is still a major endeavor. The use of simulation as a vehicle for understanding issues of organizational decision-making has gained considerable attention and momentum in recent years (Feign *et al.* (1996), Kumar *et al.* (1993) and Maloni, and Benton (1997)). Towill *et al.* (1992) used simulation techniques to evaluate effects of various supply chain strategies on demand amplification. Tzafestas and Kapsiotis (1994) utilized a combined analytical/simulation model to analyze supply chains. Swaminathan *et al.* (1995) utilized a simulation to study the effect of sharing supplier's available-to-promise information.

Petrovic *et al.* (1998) developed a fuzzy generative supply chain model to determine target order-up-to levels of inventories along a supply chain under uncertain demand and external supply of raw materials. The results of the fuzzy model were then used as input data for an evaluative simulation model that aimed to calculate replenishment quantities during a finite planning horizon. The simulation model also provides the user with the assessment of supply chain performance. These fuzzy and simulation models, however, are confined to a single production problem with no capacity constraints. Petrovic (2001) extended these models by incorporating the element of uncertain lead times during the replenishment process into the fuzzy model and (3) WMS execution. Phase one focus on operation strategy and software selection. Phase two concerned with the detailed design and conference room pilot as well as the detailed specifications of material handling equipment solution. Phase three got involved in the construction of material handling equipment solutions, organisational structure, worker training, system testing, conversion and support. Developed a SAP R/3-based ERP architecture and a conceptual diagram in an effort to create value-oriented supply chains that enable a high level of integration and communication among all supply chain processes. Their ERP architecture consisted of three layers: presentation based on graphical user interface, application and database. Talluri (2000) proposed a goal programming model for an effective acquisition and justification and maintenance, costs, flexibility, execution accuracy and compatibility.

2.3 Proposed approach

The supply chain drivers play a significant role in supply chain management's ability to support a firm/organization's competitive strategy to maintain the competitive advantage. The supply chain management drivers are: facilities, transportation, information and inventory. The design of supply chain management drivers is as follows:

(a) Decisions regarding facilities are:

- Location
- Capacity
- Warehousing methodology
- Manufacturing systems

(b) Decisions regarding transportation are:

- Mode of transportation
- Route and network
- Logistics: Outsourcing or insourcing

- Carrier

(c) Decisions regarding information are:

- Co-ordination and information sharing
- Enabling technology
- Push or pull
- Forecasting and aggregate planning

(d) Decisions regarding inventory are:

- Cycle inventory
- Safety inventory
- Seasonal inventory
- Overall trade-off

Today, in the age of growing competition, development of decision support systems for the design of supply chain drivers has assumed a great significance. There is a strong need of adequate analysis and development of proper decision support systems for design of supply chain drivers i.e. facilities, transportation, information and inventory to maintain competitive edge. The details of these are given in figure 2.3. The appropriate decision support systems for a particular problem depend on the nature of the problem, the planning and the type of decisions that need to be made. The success of the supply chain management depends upon their drivers (i.e. facilities, transportation, information and inventory) for which development of DSS for them are quite essential. In order to accommodate the above view, the proposed approach incorporates all required analyzing methods/techniques (see figure 2.3) for development of the decision support systems for the design of supply chain drivers.

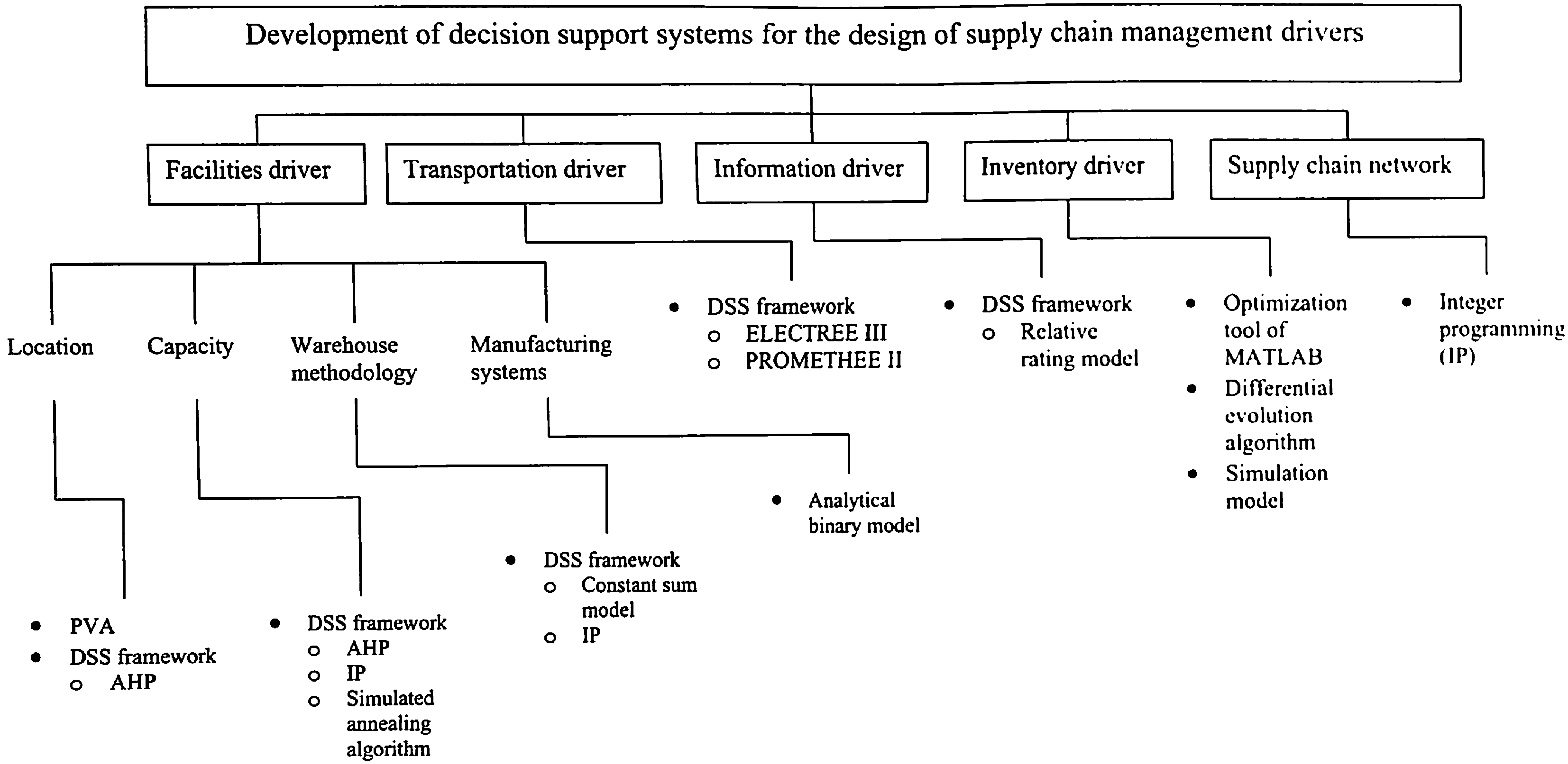

Figure 2.3: Decision support systems for the design of supply chain management drivers

2.4 Conclusions

In order to accommodate the above view, the proposed approach incorporates all the required analyzing methods/techniques for design of supply chain drivers in supply chain management. The prototype decision support systems are developed for the design of supply chain drivers in supply chain management.

References

[1] AHMED, S. and SALINITIES, N. V. (1998), "Robust Process Planning under Uncertainty", *Industrial and Engineering Chemistry Research*, vol.37, pp.1883-1892.

[2] AKKERMANS, H., PAUL, B. and BART, V. (1999), "Virtuous and vicious cycles on the road towards international supply chain management", *International Journal of Operation and Production Management*, vol. 9, pp. 565-581.

[3] ALBER, K. L. and WILLIAM, T. W. (1998), "Supply chain management: Principles and techniques for the practioner", Research paper Series, APICS Educational and Research Foundation, Falls Chruch, VA.

[4] ALEX, M. (2000), "Where's the warehouse?" *Manufacturing Engineer*, vol. 79, no. 5, pp. 214-215.

[5] AL-MASHARI, M., and ZAIRI, M. (2000), "Supply chain re-engineering using enterprise resource planning (ERP) software of a SAP R/3 implementation case", *International Journal of Physical Distribution and Logistics Management*, vol. 30, no.3/4, pp. 296-313.

[6] ALTIOK, T. and RANJAN, R. (1995), "Multi-stage, pull-type production/ inventory systems", *IIE Transactions*, vol. 27, pp.190-200.

[7] ARNTZEN, B. C., BROWN, G. G., HARRISON, T. P. and TRAFTON, L. L. (1995), "Global supply chain management at digital equipment corporation", *Interfaces*, vol. 25, pp. 69-93.

[8] ASHAYERI, J. and RONGEN, J. M. J. (1997), "Central distribution in Europe: A multi-criteria approach to location selection", *The International Journal of Logistics Management*, vol. 9, no. 1, pp. 97-106.

[9] AYERS, J. (2000), "A primer on supply chain management", *The Executive's Journal*, vol. 16, no. 2, pp. 6-15.

[10] BALLOU, R. H., STEPHEN, M. G., and MUKHERJEE, A. (2000), "New managerial challenges from supply chain opportunities", *Industrial Marketing Management*, vol. 29, no. 1, pp.7-18.

[11] BAUMOL, W. J. and VINOD, H. D. (1970), "An inventory theoretic model of freight transport demand", Management Science, vol. 16, no. 7, pp. 413-421.

[12] BEAMON, B. M. (1998), "Supply chain design and analysis: Models and methods", *International Journal of Production Economics*, vol. 55, pp. 281-294.

[13] BEAMON, M. B. (1999), "Measuring supply chain performance", *International Journal of Operation and Production Management*, vol. 19, no. 3, pp. 275-292.

[14] BECHTEL, C. and YAYARAM, J. (1997), "Supply chain management: A strategic perspective", *International Journal of Logistics Management*, vol. 8, no.1, pp. 15-34.

[15] BERRY, D. (1995), "The analysis, modeling and simulation of a re-engineered PC Supply Chain", PhD Thesis, University of Wisconsin, USA.

[16] BERRY, D., TOWILL, D. R., and WADSLEY, N. (1994), "Supply chain management in the electronics product industry", *International Journal of Physical Distribution and Logistics Management*, vol. 24, no. 10, pp. 20-32.

[17] BLUMENFELD, D. E., HALL, R. W., and JORDAN, W. C. (1985), "Trade-off between freight expediting and safety stock inventory costs", *Journal of Business Logistics*, vol. 6, no. 1, pp.79-100.

[18] BOOKBINDER, J. H., MCAULEY, P. T. and SCHULTE, J. (1989), "Inventory and transportation planning in the distribution of fine papers", *Journal of the Operational Society*, vol. 40, no. 2, pp.155-166.

[19] BOURN, M., MILLS, J., WILCOX, M., NEELY, A. and PLATTS, K. (2000), "Designing, implementing and updating performance measurement systems", *International Journal of Operations and Production Management*, vol. 20, no.7, pp.754-771.

[20] BOWERSOX, D. J. (1969), Reading in Physical Distribution Management, The logistics of marketing, Macmillan, New York.

[21] BOWERSOX, D. J. and CLOSS, D. J. (1996), "Logistical Management: The Integrated Supply Chain Process, McGraw Hill, Inc.

[22] BRADLEY, S. P., HAX, A. C. and MAGNANTI, T. L. (1977), Applied Mathematical Programming, Addison-Wesley, Reading, MA.

[23] BROWN, G. C. (1987), "Design and operation of multi-commodity production/distribution system using primal goal decomposition", *Management Science*, vol. 33, no. 11, pp.1469-1480.

[24] BUDNICK, F. S., MCLEAVEY, D. and MOJENA, R. (1988), Principles of Operations Research for Management, Irwin, Homewood.

[25] CACHON, G. P. (1999), Competitive Supply Chain Inventory Management, Kluwer Academic Publishers, Boston, MA.

[26] CALDWELL, N. S. and DOWN, S. (1997), "Faking it, supply chain relationships", Management Research News, vol. 20, no.2, pp.53-61.

[27] CAMM, J. D., CHORMAN, T. E., DILL, F. A., EVANS, J. R., SWEENEY, D. J. and WEGRYN, G. W. (1997), "Blending OR/MS judgment, and GIS: Restructuring P&G's supply chain", *Interfaces*, vol. 27, no. 1, pp.128-142.

[28] CARMEN, R. and CONRAD, S. (2000), "Key performance indicators: Putting customer first", *Supply Chain Management Review*, pp. 90-95.

[29] CHARLES, P. and BAUER, M. (2002), E-supply Chain Using the Internet to Revolutionize Your Business, Berrett-Koehler publishers, San Francisco.

[30] CHOPRA, S. and MEINDL, P. (2001), Supply Chain Management: Strategy, Planning and Operation, First Edition, Pearson Education Asia.

[31] CHRISTOPHER, M. (1998), Logistics and Supply Chain Management Strategies for Reducing Cost and Improving Service, Second Edition Published, Financial Times Professional Limited.

[32] CHRISTY, D. P. and GROUT, J. R. (1994), "Safeguarding supply chain relationships", *International Journal of Production Economics*, vol. 36, pp. 233-242.

[33] CLARK, A. J. and SCARF, H. (1960), "Optimal policies for a multi-echelon inventory problem", *Management Science*, vol.6, no. 4, pp. 475-490.

[34] COHEN, M. A. and LEE, H. L. (1988), "Strategic analysis of integrated production-distribution systems: Models and methods", *Operations Research*, vol. 36, no. 2, pp. 216-228.

[35] COHEN, M. A. and LEE, H. L. (1989), "Resource deployment analysis of global manufacturing and distribution networks", *Journal of Manufacturing and Operations Management*, vol. 2, pp. 81-104.

[36] COHEN, M. A. and MOON, S. (1990), "Impact of production scale economies, manufacturing complexity, and transportation costs on supply chain facility networks", *Journal of Manufacturing and Operations Management*, vol. 3, no. 2, pp. 269-292.

[37] COHEN, M.A. and MOON, S. (1991), "An Integrated Plant Loading Model with Economies of Scale and Scope", *European Journal of Operations Research*, vol. 50, pp. 266-279.

[38] CONSTABLE, G. K. and WHYBARK, D. C. (1978), "The interaction of transportation and inventory decisions", *Decision Sciences*, vol. 9, pp. 688-699.

[39] COOK, R. L. and ROGOWSKI, R. A. (1996), "Applying JIT principles to continuous process manufacturing supply chains", First Quarter, *Production and Inventory Management Journal*, pp. 12-17.

[40] COOKE, A. (1997), "The solid-gold supply chain", Logistics Management and Distribution Report.

[41] COOPER, M. C. and ELLRAM, L. M. (1993), "Characteristics of supply chain management and the implications for purchasing and logistics strategy", *International Journal of Logistics Management*, vol. 4, no. 2, pp.13-24.

[42] COOPER, M. C., ELLRAM L. M., GARDNER J. T., and HANKS A. M. (1997), "Meshing multiple-alliances", *Journal of Business Logistics*, vol. 18, no. 1, pp. 67-89.

[43] COOPER, M. C., LAMBERT, D. M. and PAGH, J. D. (1997), "Supply chain management: More than a new name for logistics", *International Journal of Logistics Management*, vol. 8, no. 1, pp. 1-13.

[44] COX, A. (1999), "Power, value and supply chain management", *Supply Chain Management: An International Journal*, vol. 4, pp. 192-198.

[45] COYLE, J., BARDI, E. J. and LANGLEY, J. C. (2003), "The management of business logistics, a supply chain perspective", Seventh Edition, Thomson Learning.

[46] DAS, C. (1974), "Choice of transport service: An inventory theoretic approach", *The Logistics and Transportation Review*, vol. 10, no. 2, pp.181-187.

[47] DAS, C. (1975), "Supply and redistribution rules for two-location inventory systems: One-period analysis", *Management Science*, vol. 21, no. 7, pp.765-776.

[48] DAVID, S. L., KAMINSKY, P. S., and EDITH, L. (2000), Designing and Managing the Supply Chain, McGraw-Hill.

[49] DAVIS, T. (1993), "Effective supply chain management", *Sloan Management Review*, pp. 35-46.

[50] ELLRAM, L. M. (1991), "Supply chain management: The industrial organization perspective", *International Journal of Physical Distribution and Logistics Management*, vol. 21, no.1, pp. 13-22.

[51] ELLRAM, L. M. and COOPER, M. C. (1990), "Supply chain management partnerships and the shipper-third party relationship", *International Journal of Logistics Management*, vol.1, no.2, pp.1-10.

[52] ERENGÜC, S. S., SIMPSON, N. C. and VAKHARIA, A. J. (1999), "Integrated production/distribution planning in supply chains: An invited review", *European Journal of Operational Research*, vol. 115, pp. 219-236.

[53] FEIGN, G.E., AN, C., CONNORS, D. and CRAWFORD, I. (1996), "Shape Up, Ship Put", *OR/MS Today*, vol. 23, no. 2, pp.24-30.

[54] FISHER, M. (1997), "What is the right supply chain for your product?" *Harvard Business Review*, vol. 75, no. 2, pp. 105-116.

[55] FISHER, M., HAMMOND, J., OBERMEYER, W., and RAMAN, A. (1997), "Configuring a supply chain to reduce the cost of demand uncertainty", *Production and Operations Management*, vol. 6, no. 3, pp. 211-225.

[56] FORRESTER, J. W. (1958), "Industrial Dynamics, A Major Break Through for Decision Makers", *Harvard Business Review*, vol. 36, pp.37-66.

[57] GAITHER N. and FRAZIER G. (2002), Operations Management, Thomson Asia, Singapore.

[58] GANESHAN, R., MAGAZINE, J. E. and PAUL, S. (1999), A Taxonomic Review of Supply Chain Management Research: The Quantitative Models for Supply Chain Management, Kluwer Academic Publishers.

[59] GEOFFION, A. M. and GRAVES, G. W. (1974), "Multi-commodity Distribution Design by Benders Decomposition", *Management Science*, vol. 20, pp. 822-844.

[60] GEOFFRION, A. M. and POWERS, R. F. (1995), "Twenty years of strategic distribution system design: an evolutionary perspective", *Interfaces*, vol.25, no. 5, pp.105-127.

[61] GIUNIPERO, L. C. and BRAND, R. R. (1996), "Purchasing role in supply chain management", *International Journal of Logistics Management*, vol. 7, no. 1, pp. 29-37.

[62] GLOVER, F., JONES, G., KARNEY, D., KLINGMAN, D. and MOTE, J. (1979), "An integrated production, distribution, and inventory planning system", *Interfaces*, vol. 9, no. 5, pp. 21-35.

[63] GOLDRATT, M. E., and COX, J. (1986), The Goal, North River Press, New York.

[64] HANDFIELD, R. B. and NICHOLS, E. L. (2003), Supply Chain Redesign: Transforming Supply Chains into Integrated Value System, Pearson Education Asia.

[65] HARLAND, C. M. (1996), "Supply chain management: Relationships, chains and networks", *British Academy of Management*, vol. 7, pp. S63-S80.

[66] HAUSMAN, W. H. (2000), "Supply chain performance metrics", White Paper Series on Supply Chain Trends and Developments, The Stanford Global Management Forum.

[67] HERRON, D. P. (1983), "Management science in industrial logistics", *Applications of Management Science*, vol.3, pp. 49-85.

[68] HICKS, D. A. (1999), "The state of supply chain strategy", *IIE Solutions*, pp. 24-29.

[69] HODDER, J. E. and DINCER, M. C. (1986), "A multifactor model for international plant location and financing under uncertainty", *Computers and Operations Research*, vol.13, pp. 5, pp. 601-609.

[70] HOEK, R. I. V. (1998), "Measuring the un-measurable-measuring and improving performance in the supply chain", *Supply Chain Management Review*, vol. 31, no. 4, pp. 187-192.

[71] HOPP, W. J. and SPEARMAN, M. L. (2000), Factory Physics, McGraw-Hill, Boston, MA.

[72] HOULIHAN, J. (1988), "International supply chains: A new approach", *Management Decision*, vol. 26, no.3, pp. 13-19.

[73] ISHII, K., TAKAHASHI, K. and MURAMATSU, R. (1988), "Integrated production, inventory and distribution systems", *International Journal of Production Research*, vol. 26, no. 3, pp. 473-482.

[74] IRELAND, R., and BRUCE, R. (2000), "CPFR: Only the beginning of collaboration", *Supply Chain Management Review*, vol. 4, no.4, pp. 80-88.

[75] JOHANNSON, L. (1994), "How can a TQEM approach add value to your supply?", *Total Quality Environmental Management*, vol. 3, no. 4, pp. 521-530.

[76] JOHN, T. M. (2001), Supply Chain Management, Sage Publications, California.

[77] JOHNSON, C. and WOOD, D. F. (1996), Contemporary Logistics, Prentice Hall, NJ.

[78] JOHNSON, M. E. and DAVIS, T. (1995), "Brief: Making alliances work using a computer-based management system to integrate the supply chain", *Journal of Petroleum Technology*, vol. 47, no. 6, pp. 512-513.

[79] JOHNSTON, D. A., TAYLOR, G. D. and VISWESWARAMURTHY, G. (1999), "Highly constrained multi-facility warehouse management system

using a GIS system", *Integrated Manufacturing Systems*, vol. 10, no. 4, pp. 221-232.

[80] JONES, T. C. and RILEY, W. D. (1985), "Using inventory for competitive advantage through supply chain management", *International Journal of Physical Distribution and Materials Management*, vol. 15, no. 5, pp. 16-26.

[81] KARABAKAL, N., GUNAL, A. and RITCHIE, W. (2000), "Supply-Chain Analysis at Volkswagen of America", *Interfaces*, vol.30, no.4, pp.46-55.

[82] KARMARKAR, U. S. and PATEL, N. R. (1977), "The one-period, n-location distribution problem", *Naval Research Logistics*, Quarterly, vol. 24, vol. 4, pp. 559-575.

[83] KOPCZAK, L. R. (1997), "Logistics partnership and supply chain restructuring: Survey results from the USA computer industry", *Production and Operations Management*, vol. 6, no. 3, pp. 226-247.

[84] KUMAR, A., OWN, P. S. and PERPETUAL, M. J. (1993), "Organizational simulation and information systems design: an operations level example", *Management Science*, vol. 39, no. 2, pp.218-240.

[85] KUWAITI, M. E. and KAY, J. M. (2000), "The role of performance measurement in business process re-engineering", *International Journal of Operation and Production Management*, vol. 20, no. 12, pp. 1411-1426.

[86] LALONDE, B. J. (1994), Evolution of the Integrated Logistics Concept, The Logistics Handbook, Free Press, New York.

[87] LALONDE, J. and JAMES, M. M. (1994), "Emerging logistics strategies: Blueprints for the next century", *International Journal of Physical Distribution and Logistics Management*, vol. 24, no.7, pp.35-47.

[88] LAMBERT, D. L., STOCK, J. R. and ELLRAM, L. M. (1998), Fundamentals of Logistics Management, First edition, Irwin McGraw-Hill.

[89] LAMBERT, M., MARTHA, C. C., and PAGH, J. D. (1998), "Supply chain management implementation issues and research opportunities", *International Journal of Logistics Management*, vol. 9, no.2, pp.1-19.

[90] LAMMING, R. (1996), "Squaring lean supply with supply chain management", *International Journal of Operations and Production Management*, vol.16, no. 2, pp. 183-196.

[91] LAMMING, R., (1993), Beyond Partnership: Strategies for Innovation and Lean Supply, Prentice Hall, New York, USA.

[92] LANCIONI, R. A. (2000), "New developments in supply chain management for the millennium", *Industrial Marketing Management*, vol. 29, pp. 1-6.

[93] LANGLEY, C. J. (1992), The Evolution of the Logistics Concept: The Strategic Issues, Pitman Publishing.

[94] LAPIDE, L. (2000), "Technology: True measures of supply chain performance", *Supply Chain Management Review*, pp. 25-28.

[95] LEE, H. L. and BILLINGTON, C. (1992), "Managing supply chain inventory: Pitfalls and opportunities", *Sloan Management Review*, vol. 33, no. 3, pp. 65-73.

[96] LEE, H. L. and BILLINGTON, C. (1996), "Material management in decentralized supply chains", *Operations Research*, vol. 41, no. 5, pp. 835-847.

[97] LEE, H. L. and FEITZINGER, E. (1995), "Product configuration and postponement for supply chain efficiency", *Institute of Industrial Engineers, Fourth Industrial Engineering Research Conference Proceedings*, pp. 43-48.

[98] LEE, H. L. and NG, S. M. (1997), "Introduction to the special issue on global supply chain management", *Production and Operations Management*, vol. 6, no. 3, pp.191-192.

[99] LEE, H. L., PADMANABHAN, V. and WHANG, S. (1997), "Information distortion in a supply chain: the bullwhip effect, *Management Science*, vol.43, no.4, pp. 546-558.

[100] MABERT, V. A. and VENKATARAMANAN, M. A. (1998), "Special research focus on supply chain linkages: Challenges for design and management in the 21st century", *Decision Sciences*, vol. 29, no.3, pp.537-552.

[101] MALONI, M. J. and BENTON, W. C. (1997), "Supply Chain Partnership: Opportunity for Operation Research", *European Journal of Operations Research*, vol. 10, pp.419-429.

[102] MARTHA, C. and LISA, M. E. (1993), "Characteristics of supply chain management and the implications for purchasing and logistics strategy", The *International Journal of Logistics Management*, vol. 4, no. 2.

[103] MASTERS, J. M and POHLEN, T. L. (1994), Evolution of the Logistics Profession, The Logistics Handbook, Free Press, New York.

[104] MELACHRINOUDIS, E. and MIN, H. (2000), "The dynamic relocation and phase-out of a hybrid, two-echelon plant/warehousing facility: A multiple objective approach", *European Journal of Operational Research*, vol. 123, no. 1, pp. 1-15.

[105] MELACHRINOUDIS, E., MIN, H., and MESSAC, A. (2000), "The relocation of a manufacturing/distribution facility from supply chain perspectives: A

physical programming approach", *Multi-Criteria Applications*, vol.10, pp.15-39.

[106] MENTZER, J. T. *et al.* (2001), "Defining Supply Chain Management", *Journal of Business Logistics*, vol. 22, no.2, pp.1-25

[107] MENTZER, J. T., and SCHUSTER, A. D. (1983), "Computer modeling in logistics: Existing models and future outlook", *Journal of Business Logistics*, vol. 3, no. 2, pp. 1-55.

[108] METTERS, R. (1997), "Quantifying the bullwhip effect in supply chains", *Journal of Operations Management*, vol. 15, pp. 89-100.

[109] METZ, P. (1994), "Supply chain management", Report on the state of the art; MIT Supply Chain Management Team, Centre for Transportation Studies, MIT.

[110] MICHIEL, R. L., HAROLD, E. F., FLYNN, A. E. and FRASER, J. P. (2002), Purchasing and Supply Chain Management, Twelfth Edition, McGraw Hill, New York.

[111] MIDLER, J. L. (1969), "A stochastic multi-period multimode transportation model", *Transportation Science*, vol. 3, pp. 8-29.

[112] MIN, H. and MELACHRINOUDIS, E. (1999), "The relocation of a hybrid manufacturing/distribution facility from supply chain perspectives: A case study", *Omega*, vol. 27, no. 1, 75-85.

[113] MIN, H. and MELACHRINOUDIS, E. (2001), Restructuring a Warehouse Network: Strategies and Models, Handbook of industrial engineering.

[114] MIN, H., JAYARAMAN, V., and SRISVASTAVA, R. (1998), "Combined location-routing problems: A synthesis and future research directions", *European Journal of Operational Research*, vol. 108, no. 1, pp.1-15.

[115] MONCZCKA, R., TRENT, R. and HANDFIELD, R. (2002), Purchasing and Supply Chain Management, Second Edition, Thomson Learning.

[116] MORGAN, R. and S. HUNT. (1994), "The commitment-trust theory of relationship Marketing", *Journal of Marketing*, vol. 58, pp. 20-38.

[117] NEELY, A., GREGORY, M. and PLATTS, K. (1995), "Performance measurement system design: A literature review and research agenda", *International Journal of Operation and Production Management*, vol. 15, no. 4, pp. 80-116.

[118] NEWHART D. D., STOTT, K. L. and VASKO, F. J. (1993), "Consolidating product sizes to minimize inventory levels for a multi-stage production and distribution systems", *Journal of the Operational Research Society*, vol. 44, no. 7, pp. 637-644.

[119] NICOLL, A. (1994), "Integrating logistics strategies", *Annual International Conference Proceedings–American Production and Inventory Control Society*, pp. 590-94.

[120] NORINA, L. V. and BAILEY, W. C. (2001), "Quantitative approach to supply chain relationships", *11th Annual Food and Agribusiness Symposium*, Australia.

[121] NOVACK, R. S. and SIMCO, W. (1991), "The industrial procurement process: A supply chain perspective", *Journal of Business Logistics*, vol. 12, no.1, pp.145-167.

[122] NOZICK, L. K. and TURNQUIST, M. A. (2001), "Inventory, transportation, service quality and the location of distribution centres", *European Journal of Operational Research*, vol.129, pp. 362-371.

[123] PETROVIC, D. (2001), "Simulation of supply chain behaviour and performance in an uncertain environment", *International Journal of Production Economics*, vol.71, pp. 429-438.

[124] PETROVIC, D., ROY, R., and PETROVIC, R. (1998), "Modelling and simulation of a supply chain in an uncertain environment", *European Journal of Operational Research*, vol.109, pp. 299-309.

[125] PYKE, F. and COHEN, M. A. (1994), "Multi-product integrated production-distribution systems", *European Journal of Operational Research*, vol. 74, no. 1, pp. 18-49.

[126] RICH, N. and HINES, P. (1997), "Supply chain management and time-based competition: The role of the supplier association", *International Journal of Physical Distribution and Logistics Management*, vol. 27, pp. 210-225.

[127] RICHMOND, B. and PETERS, E. (1998), Warehouse Management Systems Technologies: Technology-Enabled Warehouse Excellence: Strategic Supply Chain Alignment: Best Practice In Supply Chain Management, Gower Publishing Limited, Hampshire.

[128] ROLSTANDAS, A. (1995), Performance Measurement: A Business Process Benchmarking Approach, Chapman and Hall, New York, USA.

[129] ROSS, D. F. (1998), Competing Through Supply Chain Management Creating Market – Winning Strategies Through Supply Chain Partnerships, Chapman and Hall, USA.

[130] SAHAY, S., CAVALE, V., RAJANI, R. L., MOHAN, R. and GUPTA, P. (2001), "Supply chain practices in Indian Industries", KPMG and Management Development Institute's Joint Survey, New Delhi.

[131] SARI, H. J. (1997), Master Production Schedule; Production and Inventory control Handbook, Third Edition, McGraw Hill, New York.

[132] SCHWARZ, L. B. (1981), "Physical distribution: The analysis of inventory and location", *AIIE Transactions*, vol.13, no. 2, pp. 138-150.

[133] SCOTT, C. and WESTBROOK, R. (1991), "New strategic tools for supply chain management", *International Journal of Physical Distribution and Logistics Management*, vol. 21, no. 1, pp. 23-33.

[134] SHAPIRO, J. F. (2001), Modeling the Supply Chain, Pacific Grove, Wadsworth Group, CA.

[135] SHEIKH, K. (2001), Manufacturing Resource Planning (MRP II) With Introduction to ERP, SCM, and CRM, First Edition, Tata McGraw-Hill, New Delhi.

[136] SILVER, E. D. (1981), "Operations research in inventory management: A review and critique", *Operations Research*, vol. 29, pp. 628-645.

[137] SINGH, N. and VRAT, P. (1984), "A location-allocation model for a two-echelon repair-inventory system", *IIE Transactions*, vol. 16, no. 3, pp. 222-228

[138] SLACK, N., CHAMBERS, S. C., HARRISON, A. and JOHNSTON, R. (1995), Operations Management, Pitman, UK.

[139] SLATS, P. A., BHOLA, B., EVERS, J. J. M. and DIJKUIZEN, G. (1995), "Logistics modeling", *European Journal of Operational Research*, vol. 87, pp. 1-20.

[140] SPEKMAN, R. E., SPEAR, J., and KAMAUFF, J. (2001), "Supply Chain Competency: Learning as a Key Component", Working paper, University of Virginia.

[141] STANLEY, F. and GREGORY M. (2001), "Achieving world class supply chain alignment: Benefits, barriers and bridges", Center for Advanced Purchasing Studies.

[142] STEVENS, G.C. (1989), "Integrating the Supply Chain", *International Journal of Physical Distribution and Materials Management*, vol. 19, pp. 3-8.

[143] SWAMIDASS, P. M. (2000), Encyclopedia of Production and Manufacturing Management, Kluwer Academic Publishers, Boston, MA.

[144] SWAMINATHAN, J. M. and TOUR, S. R. (1999), Stochastic Programming Models for Managing Product Variety: Quantitative Models for Supply Chain Management, Lower Press.

[145] SWAMINATHAN, J. M., SADDEN, N. M. and SMITH, S. F. (1995), "Information Exchange in Supply Chains", Technical Report, Carnegie Mellon University, Pittsburgh, PA.

[146] SWAMINATHAN, J. M., SMITH, S. F. and SADDEN, N. M. (1998), "Modelling supply chain dynamics: A multivalent approach", *Decision Sciences*, vol.29, no.3, pp. 607-632.

[147] TALLURI, S. (2000), "An IT/IS acquisition and justification model for supply chain management", *International Journal of Physical Distribution and Logistics Management*, vol. 30, no. 3/4, pp. 221-237.

[148] TAN, K. C., KANNAN, V. R. and HANDFIELD, R. B. (1998), "Supply chain management: Supplier performance and firm performance", *International Journal of Purchasing and Material Management*, vol. 34, no. 3, pp.2-9.

[149] TAPIERO, C. S. and SOLIMAN, M. A. (1972), "Multi-commodities transportation schedules over time. Networks", *AIIE Transactions*, vol. 2, pp. 311-327.

[150] THOMAS, J. and GRIFFIN, P. M. (1996), "Coordinated supply chain management", *European Journal of Operations Research*, vol. 94, pp. 1-15.

[151] TOWILL, D. R. (1997), "Supply chain dynamics", *International Journal of Computer Integrated Manufacturing*, vol. 4, no. 4, pp. 197-208.

[152] TOWILL, D. R., NAIM M. M. and WIKNER, J. (1992), "Industrial dynamics simulation models in the design of supply chains", *International Journal of Physical Distribution and Logistics Management*, vol. 22, no. 5, pp. 3-13.

[153] TSAY, A., NAHMIAS, S., and AGRAWAL, N. (1998), Modelling Supply Chain Contracts: A Review, Kluwer Academic Publishers, Boston, MA.

[154] TURNER, R. (1993), "Integrated supply chain management: What's wrong with picture?", *Industrial Engineering*, vol. 25, no. 12, pp. 52-55.

[155] TYNDALL, G., CHRISTOPHER, G. P., WOLFGANG, and JOHN, K. (1998), Supercharging Supply Chains, John Wiley and Sons, New York.

[156] TZAFESTAS, S. and KAPSIOTIS, G. (1994), "Coordinated control of manufacturing/supply chains using multi-level techniques", *Computer Integrated Manufacturing Systems*, vol. 7, no. 3, pp. 206-212.

[157] VOUDOURIS, V. T. (1996), "Mathematical programming techniques to de-bottleneck the supply chain of fine chemical industries", *Computers and Chemical Engineering*, vol. 20, pp. 1269-1274.

[158] WAGGONER B., NEELY, A. D. and KENNERLEY, M. P. (1999), "The forces that shape organizational performance measurement systems: An interdisciplinary review", *International Journal of Production Economics*, vol. 60, pp. 53-60.

[159] WALTON, W. L. and MILLER, G. L. (1995), "Moving towards LIS theory development: A framework of technology adoption within channels", *Journal of Business Logistics*, vol. 16, no.2, pp. 117-223.

[160] WEBER, C. A., CURRENT, J. R., and BENTON, W. C. (1990), "Vendor selection criteria and methods", *European Journal of Operational Research*, vol. 50, pp. 2-18.

[161] WEMMERLOV, U. (1984), "Assemble to order manufacturing: Implication for materials management", *Journal of Operations Management*, vol. 4, no. 4.

[162] WIKNER, J., TOWILL, D. R. and NAIM, M. (1991), "Smoothing supply chain dynamics", *International Journal of Production Economics*, vol. 22, no. 3, pp. 231-248.

[163] ZIPKIN, P. H. (2000), Foundations of Inventory Management, McGraw-Hill, New York.

Chapter 3

Design of Facilities Driver in Supply Chain Management

3.1 Introduction

The supply chain is made up of all the activities that are required to deliver the products to customers. It includes procuring materials, designing the product, receiving orders, manufacturing, logistics, marketing, customer relations and so on. Effectively integrating the information and material flows within the demand and supply process is what supply chain management is all about. So it takes decisions regarding where to locate the plant and distribution centre (location decision), how much to produce at each site (capacity decision), how to source/distribute the raw material/product (transportation decision), how to share the information among the parties (information decision) and what quantity of goods to hold at each stage of the supply chain (inventory decision). Over the past few years, as combination of economic, technology and market forces have compelled organizations to examine and rethink the supply chain strategies. Some of these forces include the globalization of business, proliferation of product variety, increasing complexity of supply chain networks and the shortening of the product life cycles. To stay competitive, enlightened organizations have strived to achieve greater coordination and collaboration among supply chain partners, in an approach called 'competitive supply chain'. It is the integration of traditional supply chain and e-supply chain, which offers the benefits of traditional supply chain and e-supply chain. So while taking either strategic or operational decisions in competitive supply chain, one has to consider the impact of the decision making on all the members of the chain.

3.2 Development of decision support systems for selection of facilities location

In competitive supply chain network, facilities location includes location of manufacturing plant, which is considered as supply chain design or strategic decision and involved in major capital investments and has a long-term effect on the supply chain performance. For example the location of a multibillion-dollar automobile assembly plant can not be changed as a result of changes in customer demands, transportation costs or component prices. Therefore the successful execution of this decision would give cutting edge to the organization. Site selection may be relatively easy for small regional company but very complex for large multinationals where many factors come into play. Now most of the multinationals break down their production process into various stages and it is spread across global. This spatial fragmentation of production aims at taking advantage of differences in technologies, factor endowments or factor prices across places. Global expansion offers access to new markets and opportunities to utilize economies of scale. However, in order for expansion to be successful firms must identify facility sites that offer a good fit with their internal strengths and weaknesses. While an organization wants to pursue global expansion, it should fully understand the multiple relationships when locating in a new business environment. Dymsza (1972) discussed complex issues associated with global expansion include:

- The firm must deal with multiple political, economic, legal, social and cultural environments as well as various rates of change within each of them.
- Interactions between the national and foreign environments are complex because of national sovereignty issues and widely differing economic and social conditions.

- Geographical separation, cultural and national differences, and variations in business practices all tend to make communication between headquarters and overseas affiliates difficult.
- Analysis of present and future competition may be more difficult to undertake in a number of countries because of differences in industrial structure and business practices.
- The degree of significant economic, marketing and other information required for planning varies a great deal among countries in availability, depth, and reliability.

The advent of increased globalisation and greater communication efficiency has provided the impetus for companies to develop and expand their global facility and supply chain networks. Firms that fail to construct efficient global facility networks will suffer a significant competitive disadvantage. With access to the whole world, a manager's facility location decision becomes considerably more challenging not only due to differences in investment and operating costs among countries but also due to government-subsidized financing, trade tariffs, regional trade rules, local content rules, and tax differences. Over the years one of the most prominent corporate growth strategies has been the expansion into global markets (Hoffman, 1994). Global expansion offers access to new markets and opportunities to utilize economies of scale. The rapid expansion of world-wide competition has forced many firms to move their production bases across national borders in order to gain competitive advantage, as well as providing better an d faster customer service. Making decisions on location for the production of products is a key aspect of st rategic and logistical decision making for manufacturing firms as they shape the entire logistics system. The optimum locations may offer competitive advantage and may contribute to the success of an enterprise. The number of firms considering location on a worldwide basis continues to increase (Flaherty, 1996). A very wide range of factors may potentially influence firms in deciding to locate production facilities across national boundaries. One of the most important and far reaching decisions faced by operations managers is deciding where to locate new manufacturing facilities. This is a strategic decision involving irreversible allocation of the firm's capital and often has a crucial impact on key measures of the firm's supply chain performance such as lead time, inventory, responsiveness to demand variability, flexibility, and quality. With the emergence of efficient supply chain management as an important frontier of competition, the facility location decision becomes even more significant. Facility location is a long-term business strategic decision for a distribution company. A basic location problem consists of locating a number of facilities or depots to supply a set of customers. The objective is to minimize the cost of locating the facilities and assigning the customers to them. This problem has been extensively studied in the literature and is commonly referred to as the plant location problem, or facility location problem (Baldacci *et al.*, 2002). For many years, the facilities location problem has attracted a great deal of attention in the management literature. As a result, there is now a variety of methods for solving these problems. The facilities location literature dealing with quantitative modelling is quite extensive. Thizy *et al.* (1980), and Brandeau and Chiu (1989) provided an extensive survey of the literature in this area. The other conventional approaches to location selection include heuristics (Berman *et al.*, 2001 and Klose, 1999), integer programming (Melkote and Daskin, 2001), dynamic programming (Canel, 2001), nonlinear programming (Nanthavanij and Yenradee,1999) multi-objective goal programming (Badri,1999), non-convex programming (Butt *et al.*, 1996), quadratic programming (Comley, 1995), analog approach (Applebaum, 1968) analytic hierarchy process (Badri, 1999), multi-attribute utility method (Benjamin *et al.*, 1995), multiple regression analysis (Nobuaki *et al.*, 1998), and branch and bound method (Canel, 2001). These approaches can only provide a set of systematic steps for problem solving without considering the relationships between the decisions factors globally. Moreover, the ability and experience of the analyst(s) may also influence significantly the final outcome. In addition, artificial intelligence techniques, such as expert systems, artificial neural networks (ANNs), and fuzzy set theory are used in location selection. Wang and Malakooti (1992) presented a feed forward neural network using the golden section descent technique for multiple criteria decision-making. Benjamin *et al.* (1995) compared the performance of ANNs as classifiers in the facility location domain. Adaptive resonance theory and back propagation paradigms are used as exemplars of ANNs developed using supervised and unsupervised learning. Jungthirapanich (1992) developed a decision support system incorporated a database management system, a linear additive multi-attribute utility method, an expert system, and graphical support. Tzeng and Chen (1999) proposed a location model based on a fuzzy multi-objective approach. The model helps in determining the optimal number and sites of stations at an international airport, and also assists the relevant authorities in drawing up optimal locations for fire stations. Kuo *et al.* (1999) developed a decision support system using the fuzzy sets theory being integrated with analytic hierarchy process for locating a new convenience store. Chen, C. T. (2001) and Chen, S. M. (2001) proposed a new multiple criteria decision-making method to solve the distribution centre location selection problem under fuzzy environment. Kuo *et al.* (2002) developed a decision support system for locating convenience store. A complete bibliography on facility location applications and methods can be found in Drezner (1995). Ghosh and Harche (1993) identified major developments in the literature that have been critical in the application of location-allocation models in the private sector. One important reason for their popularity is the ability of these models to determine the optimal location of several facilities simultaneously. Handler and Mirchandani (1979) have classified location problems in several ways based on the type of objective function, the point of demand, the potential facility site and the number of facilities to be located. Many models have been developed in the literature that develops different procedures for the problem of selecting a facility site. Ross and Soland (1980) utilized a discrete model and considered objectives such as the average travel time, maximum travel time, the number of facilities, the total system cost, and the utilization of the facilities. However, the paper considered only one criterion at a time, except through the use of constraints, and no consideration was given to trade-offs among several criteria. ReVelle *et al.* (1977) discussed the multi-attribute aspects of fire station location and cite coverage of fires, area, population, property value, property value hazard and population hazard as criteria to be maximized. Human endeavours generally have many objectives. Many methodologies have been utilized to solve the location-allocation problem (Lee et. al, 1981). The more obvious methodology has been the fundamental transportation/ assignment, and linear programming formulation. Integer and mixed integer formulations has been applied by many researchers (Toregas *et al.*, 1971, Meyer, 1973, Jucker and Carlson, 1976, Kennington and Unger, 1976, Mairs, 1978 and Patel, 1979). Baumol and Wolfe (1958) have solved the location problem for minimum total delivery cost with nonlinear programming. Others have incorporated stochastic functions to account for such distributions as demand and/or supply (Wesolowsky, 1977, Rosenthal *et al.*, 1978, and Harrison, 1979). Other methodologies that have been employed include dynamic programming (Erlenkotter, 1975, Rosenthal et. al., 1978, Wesolowsky and Truscott, 1975 and Sweeny and Tatham, 1976), multivariate statistics such as multidimensional scaling (Amador and Starbird, 1989) and heuristic and search procedures (Kuehn and Hamburger, 1963 and Walker, 1976). Haley (1962) presented a problem of determining the number and location of depots and allocating the quantities of product to depots. A method called mechanical analogue is used which minimizes the overall cost. Yoon and Wang (1985) addressed the location of single plant with qualitative and quantitative data. Median ranking method and TOPSIS methods are discussed. It is concluded that solution to MADM analysis is a compromised one not an optimal one. Hodder and Dincer (1986) presented the international plant location problem model which is a large-scale nonlinear MIP and it is very difficult to solve. Barda *et al.* (1990) addressed the problem of location of thermal power plant. They used ELECTRE as technique to find the best location. It is concluded that the method is suitable for industrial sitting problems. Cohen and Moon (1991) presented a mixed integer, multi-commodity model to find inbound raw material flows, assignment of product lines and specification of production volumes, and outbound finished product flows in a production-distribution network. Schmenner (1994) is concentrated on uncovering the factors that influence the service operation's location decision. Yurimoto and Masui (1995) designed a decision support system in order to give appropriate information to manufacturers who are going to set up plants. Sridharan (1995) provided a review of the various solution methods for the capacitated plant location problem. Badri *et al.* (1995) studied industrial location analysis, three models were developed which supplement or complement traditional approaches of industrial location analysis. Yoon and Hwang (1995) addressed a multi-plant location strategy and relocation problem. Ordinal intersection method and AHP process has been considered. Hoffman and Schniederjans (1996) provided a powerful decision-making tool for country and facility site selection, the information it generates with duality and sensitivity analysis possesses some limitations. Hoffman and Schniederjans (1996) presented a two-stage model that combines the concepts of strategic management, the management science technique of goal programming, and microcomputer technology to provide managers with a more effective and efficient method for evaluating global facility sites and making selection decisions. Freese (1997) considered the problem of location of new plant or distribution centre. Yang and Lee (1997) presented an AHP decision model for facility location selection from the view of organizations which contemplate locations of a new facility or relocation of the existing facilities. Owen and Daskin (1998) have attempted to provide an overview of facility location literature dedicated to capturing the complex time and uncertainty characteristics of most real-world problem instances. Korpela and Lehmusvaara (1999) designed warehouse network based on both quantitative and qualitative data. The AHP process and mixed integer programming method is being used. The model is strongly customer driven rather than supply driven. Atthirawong and Maccarthy (2001) identified a comprehensive set of international location decision factors through Delphi study. MacCarthy and Attirawong (2001) explored critical factors that influence international location decisions in real world situations. Canel and Das (2002) presented a mathematical model for global facility location that integrates marketing and manufacturing decisions in a global context. Remer and Mattos (2003) presented the study on cost and location factors in the US and internationally. Goldengorin *et al.* (2004) presented branch and peg algorithms for the simple plant location problem. These algorithms make two improvements on the basic branch and bound scheme. Factors influencing international location decisions are discussed by Badri et al. (1995), Hoffman and Schniederjans (1994) and Canel and Khumawala (1996). Jungthirapanich and Benjamin (1995) provided a chronological summary of research studies undertaken between 1875 to 1990 on general industrial location, revealing that, frequently in the past, a limited number of quantitative factors such as transportation and labour costs were considered when firms made a location decision, but that more recently an increasingly wide range of both qualitative and quantitative factors have been evident. Costs are a major consideration in many international location decisions and there may be trade-offs between different types of costs. Qualitative issues such as social and political factors are also influential in many international location decisions. A survey conducted by Badri *et al.* (1995) indicated that global competition and economic-related factors are more notable than conventional location factors such as transportation costs and climate when firms decide to do business abroad. A number of factors such as financial incentives and tax structure may be influenced or controlled by host governments and such factors will vary from country to country. The importance of the various factors may change significantly over time (Epping, 1982). Location factors can be considered and classified in a variety of ways (Lee and Franz, 1979; Epping, 1982; Sule, 1994; Hoffman and Schniederjans, 1994; Barkley and McNamara, 1994; Burnham, 1994; Badri *et al.*, 1995; Chase and Aquilano, 1995; Dilworth, 1996; Badri, 1996; Russell and Taylor, 1998; Dorneir *et al.*, 1998; Badri, 1999). A detailed study of the literature was made to identify a fully comprehensive set of factors and sub-factors that are potentially relevant to international location decisions (Atthirawong and MacCarthy, 2000; MacCarthy and Atthirawong, 2001). A number of techniques have been advocated in the literature to aid location decision making (Brandeau and Chiu, 1989; Sule, 1994; Revelle and Laporte, 1996; Hayter, 1997). Several researchers (Douglas and Craig, 1989; Kogut, 1984;

Levitt, 1983; McDonald, 1986; Porter, 1985) provided insights to this globalization process and how companies faced with foreign competition can maintain their competitiveness. Several factors influence decisions on investing abroad and choosing foreign manufacturing locations. Bass *et al.* (1977) and Tong and Walter (1980) conducted surveys to identify the factors to be considered in establishing manufacturing facilities in other countries. In addition to these two surveys, several other studies (Haug, 1985; Ferdows, 1989; Naik and Chakravarty, 1994; Yip, 1993) outline the following factors as the most common and influential ones: labor and other production inputs, political stability, host government attitudes toward foreign investment, host government tax and trade policies, proximity to major markets, access to transportation and existence of other competitors. Location-allocation decisions involve a substantial capital investment and result in long-term constraints on production and distribution of goods. These problems are complex and, like most real world problems depend upon a number of tangible and intangible factors which are unique to each problem. The complexity stems from a multitude of quantitative and qualitative factors influencing location choices as well as the intrinsic difficulty of making numerous trade-offs among those factors. Furthermore, significant changes in the operating environment add to the complexity of the decision process. These changes include demand for flexible services integrated with the customer's logistics systems, realisation of demand/performance interactions, reduction of reaction and response times and increased replenishment cycle lead times due to globalized sourcing channels (Closs and Thompson, 1992). Closs and Thompson (1992) presented three generalisations concerning the management of physical assets in a logistical system. The phases of the warehouse site selection process have been described e.g. by Stock and Lambert (1987). The warehouse site selection decision is a process during which multiple criteria must be considered (Gattorna, J. *et al.*, 1988). Cooper (1990) identified the following factors to be taken into account: the total costs of the distribution system, market orientation, production operation, the nature of the product, communications, financial considerations, the type of warehouse, and local considerations. Weber (1929) stated "by location factor we mean an advantage which is gained when an economic activity takes place at a particular point or at several such points rather than elsewhere". A comprehensive list of location factors that is considered at different period of time by different researchers is given in table 3.1.

Table 3.1: Location factors at different period of time

Authors	Factors considered
Tong (1979)	• Nearness to markets within the US • Proximity to export markets • Nearness to home operations • Nearness to operations in a third country • Facilities of import and export • Proximity to raw material sources • Proximity to suppliers • Availability of managerial and technical personnel • Availability of skilled labor • Availability of unskilled labor • Salary and wage rate • Labor attitudes • Labor laws

	• Availability of utilities • Cost of utilities • Availability of transportation facilities • Cost of transportation facilities • Availability of suitable plant sites • Cost of suitable land • Cost of construction • Ample space for future expansion • Availability of local capital fund • Cost of local capital fund • State tax rates • Local tax rates • Government incentives • Attitudes of government officials • Attitudes of local citizens • Housing facilities • Education facilities • Police and fire protection
Schmenner (1982)	• Labor costs • Labor unionization • Transportation costs • Proximity to raw materials

	• Proximity to existing company facilities • Quality of life
Hax and Majluf (1983)	• Economic factors • Technological factors • Governmental factors • Social factors • Industry factors
Watts (1987)	• Labor factors • Accessibility factors • Community factors • Business climate factors • Utility factors • Plant site factors • Financial and special factors
Badri, Davis and Davis (1995)	• Availability of airway facilities • Availability of waterway facilities • Availability of pipeline facilities • Availability of unskilled labour • None existence of unions • Cost of living • Worker stability • Closeness of materials

	• Freight cost • Anticipation of growth of markets • Shipping costs to markets • Attainment of favourable competitive position • Income trends • Size of markets • Cost of industrial land • Cost of developed industrial park • Acreage required • Insurance rates • Closeness to other industries • Availability of fuel • Availability of electric power • Zoning codes • Safety inspections • Industrial property tax • Living conditions • Relative humidity • Monthly average temperature • Availability of colleges • Religious facilities • Attitude of community leaders

	• Availability of shopping centres • Availability of hotels and motels • Community position of future expansion
Yurimoto and Masui (1995)	• Labor • Markets • Transportation • Financial inducement • Living conditions
Vos (1997)	• Supply of materials • Labor • Capital • Energy • Distribution • Technology intensity • Control intensity • Labor/capital ratio • Value density
Ulgado (1996)	• Local and labor attitudes • Community environment • Incentives • Land and transportation services • International concerns

	• Synergy logistics • Input logistics • Capital concerns • Market logistics • Skilled HR availability • Tax rates
Yang and Lee (1997)	• Access to markets/distribution centres • Access to supplies/resources • Community/government access • Competitive considerations • Environmental factors • Labour • Taxes and financing • Transportation • Utilities services
Hayter (1997)	• Transportation facilities • Materials • Markets • Labor • External economies • Energy • Community Infrastructure

	• Capital • Land/Buildings • Environment
Brush *et al.* (1999)	• Proximity to import markets • Proximity to key customers • Proximity to key suppliers • Proximity to other facilities • Access to raw materials • Access to energy • Access to capital • Access to local technology • Access to skilled labor • Access to low cost labor • Access to protected markets • Tax conditions • Regional trade barriers • Government subsidies • Exchange rate risk • Language, culture, politics • Advanced infrastructure • Labor practices & regulations • Environmental regulations

Atthirawong and MacCarthy (2001)	• Favorable labor climate • Transportation costs • Proximity to markets and customers • Proximity to suppliers and resources • Proximity to parent company's facilities • Location of competitors • Quality of environment • Political factors • Tax structure related factors • Social factors • Economic related factors • Other related factors
Vereecke and Dierdonck (2002)	• Proximity to suppliers • Availability of labor • Availability of skills and know-how • Proximity to market • Socio-political • Competition • Energy

3.2.1 Development of performance value analysis model for selection of facilities location

In recent years, the competitive supply chain has been widely considered for implementation to maintain competitive advantage. Company X is involved in an automotive production and case situation is discussed in table 3.2. Most of the products are world-class and supply chain is a key competitive factor in the business. The logistics executives now face the problem to develop the competitive supply chain. Based on preliminary analysis, the logistics executives identified three possible locations for facilities i.e. location A, location B and location C. However, the implementation of such systems is expensive and relative investments tend to be irreversible, thus necessarily requiring careful consideration before a decision can be made. The decision making process depends upon both qualitative and quantitative criteria involving a lot of factors/attributes. The decision support system i.e. performance value analysis (PVA) model is well received in literature (D'Angelo *et al.*, 1996a, 1996b). This model is revised version of utility value analysis. PVA model is introduced with respect to different objectives, considering appropriate performance indicators related to Workforce (W), Social and culture (S), Infrastructure (I), Suppliers (V), Markets and Customers (M), Economy (E), Government and policies (G), Legal and regulatory (L), Costs (C) and Characteristics of location specific (P). The performance value analysis, a multi-criteria technique that aggregates the multiple criteria, is here applied on data obtained from literature and experts.

Table 3.2: Case situation

Supply chain strategy	Somewhat responsive
Type of organization	Automotive production
Organizational culture	Moderate risk taking
Product strategy	Moderate profit margin and supplier risk

3.2.1.1 Algorithm

The steps to follow in using the performance value analysis are:

Step 1 Define the problem and determine the objective.

Step 2 Identify the alternatives (a_i) available. (The alternatives are: Location A, Location B, and Location C).

Step 3 Determine the attributes/criteria/performance indicators (c_j) that govern the problem.

Step 4 Classify the attributes/criteria/performance indicators into significant categories.

Step 5 Classify the attributes/criteria/performance indicators into direct (performance grows while measure increases) and indirect categories (performance grows while measure decreases). (Steps 3, 4, and 5 are shown in table 3.3)

Step 6 Form the performance matrix, i.e., co-efficient e_{ij} related to the attribute/criterion/performance indicator c_j (j = 1, 2 ...J) and the alternative a_i (i=1, 2 ...I) (see table 3.4)

Step 7 Quantify the qualitative attributes using the scale of 1 to 10, where 1 means very low, 3 means low, 5 means medium, 7 means high, and 9 means very high.

Step 8 Absolute weightage w_j on a suitable scale (say 1 to 10) is assigned for each attribute/criterion/performance indicator reflecting the normative judgment of the decision maker.

Step 9 Form the normalized performance matrix. It is transforming the initial performance measure in a score/weight for easier interpret based on the value function f_i for each attribute/criterion/ performance indicator (c_j) as follows:

i. Direct category (when performance increases while measure increases)

$$p_{ij} = \frac{e_{ij}}{\max(e_j)}$$ for each alternative a_i related to attribute c_j

ii. Indirect category (when performance grows while measure decreases)

$$p_{ij} = \frac{\min(e_j)}{e_{ij}}$$ for each alternative a_i related to attribute c_j

The normalized performance matrix is given in table 3.5.

Step 10 Obtain the relative weight-age for each attribute/criterion/performance indicator (c_j) from absolute weight-age w_j:

$$\overline{W_j} = \frac{w_j}{\sum w_j} \quad \text{such that } \sum \overline{W_j} = 1$$

Step 11 Obtain partial performance measure Z_{ij} by multiplying relative weightage $\overline{W_j}$ of attribute/criterion/performance indicator to each of its row members (alternatives), i.e., p_{ij} as: Partial performance of j^{th} attribute:

$$Z_{ij} = p_{ij} \times \overline{W_j} \quad (i = 1, 2 \ldots I)$$

Step 12 Aggregate the partial performance measures for each alternative as: overall measure (N_i) of alternative a_i is the sum of Z_{ij}

$$N_i = \sum_{j=1}^{J} Z_{ij}$$ (Steps 10, 11, and 12 are shown in table 3.6).

Step 13 Rank the alternatives (a_i) in accordance with decreasing value of N_i

Step 14 Perform the significant category analysis. The results of this analysis are obtained by setting to zero the weights of each attribute/criterion/performance indicator different from the significant category being considered. Run step 8 to step 13. Repeat the step 14 for all significant categories.

Step 15 Take the decision based on above aggregated partial performance measures and the aggregated performance measures of significant categories (see table 3.7).

Highly user-friendly software, the decision support system i.e. PVA model is developed in VC++ to aid the user to compute the partial performance measures for all performance indicators/attributes/ criteria and to compute the significant category analysis. The weightage of the attributes is given with respect to the case situation discussed in table 3.2. The decision can be taken based on the figures (figures 3.1-3.13) and table 3.7 generated by the developed software.

Table 3.3: Criteria/attributes/performance indicators

Criteria/attributes/performance indicators	Notation	Direct/ Indirect	Significant category
Quality	[QUL]	▲	W
Availability (number)	[ALF]	▲	W
Attitude	[ATT]	▲	W
Motivation	[MOT]	▲	W
Unions (number)	[UIN]	▼	W
Unemployment rate (%)	[UNR]	▼	W
Productivity(units of output per man-hour)	[PRD]	▲	W
Cost of living ($/month/person)	[COL]	▼	S

Community cooperation and attitude	[CCA]	▲	S
Communicative Language	[CLG]	▼	S
Quality of life	[QLL]	▲	S
Culture	[CUL]	▲	S
Transport systems	[TSS]	▲	I
Telecommunication systems	[TES]	▲	I
Utilities (energy and water)	[UTL]	▲	I
Business/support services (IT, financial/legal)	[BSS]	▲	I
Logistics providers (number)	[LOP]	▲	I
Availability (number)	[AVA]	▲	V
Quality	[QUS]	▲	V
Reliability of supply process system	[RLS]	▲	V
Flexible	[FLS]	▲	V
Continuous improvement commitment	[CIS]	▲	V
Responsiveness (days)	[RES]	▼	V
Proximity (km)	[PRS]	▼	V
Size of market (%)	[SIM]	▲	M
Proximity (km)	[PXK]	▼	M
Population trends (%)	[POT]	▲	M
Growth potential (%)	[GRP]	▲	M
Receptivity	[REP]	▲	M
Type	[TYP]	▲	E
Tax structure and tax incentives (%)	[TAT]	▲	E
Custom duties (%)	[CUD]	▼	E
Tariffs (%)	[TAR]	▼	E
Inflation (%)	[INN]	▼	E
Business climate	[BUC]	▲	E
Country's debt (millions $)	[COB]	▼	E
Interest rates/exchange controls (%)	[INC]	▼	E
GDP/GNP growth (%)	[GGG]	▲	E
Stability and consistency	[STC]	▲	G
Transparency	[TRP]	▲	G

Government support and attitude	[GSA]	▲	G
International relations	[ITR]	▲	G
Compensation laws	[CLL]	▲	L
Insurance laws	[INL]	▲	L
Environmental regulations	[ENR]	▲	L
Industrial relation laws	[IRL]	▲	L
Legal systems	[LES]	▲	L
Corporate investment regulations	[CIR]	▲	L
Import/Export regulations	[IER]	▲	L
Regulations concerning joint ventures and mergers	[RJM]	▲	L
Regulations on transfer of earnings rate out of country (%)	[RCE]	▲	L
Labour ($/day)	[LAB]	▼	C
Land ($/unit)	[LAN]	▼	C
Inbound logistics (millions $)	[ILC]	▼	C
Outbound logistics (millions $)	[OLC]	▼	C
Operating (millions $)	[OPE]	▼	C
Construction/leasing (millions $)	[CNL]	▼	C
Utilities (energy, water supply) ($/unit)	[UTC]	▼	C
Availability of space for the future expansion	[AFE]	▲	P
Physical conditions	[PHC]	▲	P
Proximity to parent company's facilities (km)	[PCF]	▼	P
Location of competitors (number)	[LCC]	▲	P
Proximity to raw materials/resources (km)	[PRR]	▼	P
Location of suppliers (number)	[LOS]	▲	P
The best value is the lowest one (Indirect) ▼ The best value is the highest one (Direct) ▲			

Table 3.4: Performance matrix

Notation	Weight	Location A	Location B	Location C
[QUL]	5	High	Medium	Low
[ALF]	10	5000	9000	3000
[ATT]	5	Very High	Low	Very Low
[MOT]	5	Very High	Very Low	Very Low
[UIN]	8	5	2	2
[UNR]	3	40	40	80
[PRD]	8	80	60	50
[COL]	10	200	800	500
[CCA]	10	Medium	Low	High
[CLG]	5	High	Medium	Low
[QLL]	4	High	Medium	Low
[CUL]	5	Very High	Medium	Low
[TSS]	10	High	Low	Low
[TES]	8	Very High	Low	Very Low
[UTL]	10	Very High	Low	Very Low
[BSS]	8	Very High	Medium	Very Low
[LOP]	4	4	9	3
[AVA]	6	20	10	7
[QUS]	8	High	Medium	Low
[RLS]	4	Very High	Medium	Low
[FLS]	10	Medium	High	High
[CIS]	10	Very High	Medium	High
[RES]	4	5	7	10
[PRS]	10	150	300	600
[SIM]	10	25	45	60
[PXK]	10	100	200	500
[POT]	8	4	2	2
[GRP]	8	5	3	3

[REP]	4	Very High	Medium	Low
[TYP]	10	Medium	High	High
[TAT]	8	40	15	10
[CUD]	6	30	50	100
[TAR]	4	20	40	70
[INN]	8	10	6	4
[BUC]	10	High	Medium	Low
[COB]	10	300	500	1000
[INC]	3	10	8	8
[GGG]	8	10	4	3
[STC]	10	Medium	High	Low
[TRP]	7	High	Medium	Low
[GSA]	7	High	Medium	Very Low
[ITR]	7	Very High	Medium	Low
[CLL]	7	Very High	Low	Medium
[INL]	7	Low	Medium	High
[ENR]	6	Low	Medium	High
[IRL]	6	High	Medium	Low
[LES]	7	High	Medium	Low
[CIR]	7	Medium	Very High	High
[IER]	4	High	Low	Very Low
[RJM]	4	High	High	low
[RCE]	3	40	60	80
[LAB]	9	40	80	50
[LAN]	10	35	65	90
[ILC]	9	45	75	100
[OLC]	9	30	60	90
[OPE]	6	60	50	40
[CNL]	5	100	50	40
[UTC]	10	5	7	9

[AFE]	10	Very High	Low	Very Low
[PHC]	8	Very High	Low	Very Low
[PCF]	8	4000	2000	1000
[LCC]	5	4	2	3
[PRR]	6	100	400	600
[LOS]	7	8	4	2

Table 3.5: Normalized performance matrix

Notation	Weight-age	Location A	Location B	Location C
[QUL]	0.0108	1.000	0.625	0.375
[ALF]	0.0217	0.556	1.000	0.333
[ATT]	0.0108	1.000	0.333	0.111
[MOT]	0.0108	1.000	0.111	0.111
[UIN]	0.0174	0.400	1.000	1.000
[UNR]	0.0065	1.000	1.000	0.500
[PRD]	0.0174	1.000	0.750	0.625
[COL]	0.0217	1.000	0.250	0.400
[CCA]	0.0217	0.714	0.429	1.000
[CLG]	0.0108	0.429	0.600	1.000
[QLL]	0.0087	1.000	0.714	0.429
[CUL]	0.0108	1.000	0.556	0.333
[TSS]	0.0217	1.000	0.429	0.429
[TES]	0.0174	1.000	0.333	0.111
[UTL]	0.0217	1.000	0.333	0.111
[BSS]	0.0174	1.000	0.556	0.111
[LOP]	0.0087	0.444	1.000	0.333
[AVA]	0.0130	1.000	0.500	0.350
[QUS]	0.0174	1.000	0.714	0.429
[RLS]	0.0087	1.000	0.556	0.333
[FLS]	0.0217	0.714	1.000	1.000

[CIS]	0.0217	1.000	0.556	0.778
[RES]	0.0087	1.000	0.714	0.500
[PRS]	0.0217	1.000	0.500	0.250
[SIM]	0.0217	0.417	0.750	1.000
[PXK]	0.0217	1.000	0.500	0.200
[POT]	0.0174	1.000	0.500	0.500
[GRP]	0.0174	1.000	0.600	0.600
[REP]	0.0087	1.000	0.556	0.333
[TYP]	0.0217	0.714	1.000	1.000
[TAT]	0.0174	1.000	0.375	0.250
[CUD]	0.0130	1.000	0.600	0.300
[TAR]	0.0087	1.000	0.500	0.286
[INN]	0.0174	0.400	0.667	1.000
[BUC]	0.0217	1.000	0.714	0.429
[COB]	0.0217	1.000	0.600	0.300
[INC]	0.0065	0.800	1.000	1.000
[GGG]	0.0174	1.000	0.400	0.300
[STC]	0.0217	0.714	1.000	0.429
[TRP]	0.0152	1.000	0.714	0.429
[GSA]	0.0152	1.000	0.714	0.143
[ITR]	0.0152	1.000	0.556	0.333
[CLL]	0.0152	1.000	0.333	0.556
[INL]	0.0152	0.429	0.714	1.000
[ENR]	0.0130	0.429	0.714	1.000
[IRL]	0.0130	1.000	0.714	0.429
[LES]	0.0152	1.000	0.714	0.429
[CIR]	0.0152	0.556	1.000	0.778
[IER]	0.0087	1.000	0.429	0.143
[RJM]	0.0087	1.000	1.000	0.429
[RCE]	0.0065	0.500	0.750	1.000

[LAB]	0.0195	1.000	0.500	0.800
[LAN]	0.0217	1.000	0.538	0.389
[ILC]	0.0195	1.000	0.600	0.450
[OLC]	0.0195	1.000	0.500	0.333
[OPE]	0.0130	0.667	0.800	1.000
[CNL]	0.0108	0.400	0.800	1.000
[UTC]	0.0217	1.000	0.714	0.556
[AFE]	0.0217	1.000	0.333	0.111
[PHC]	0.0174	1.000	0.333	0.111
[PCF]	0.0174	0.250	0.500	1.000
[LCC]	0.0108	1.000	0.500	0.750
[PRR]	0.0130	1.000	0.250	0.167
[LOS]	0.0152	1.000	0.500	0.250

Table 3.6: Partial performance measures

Criteria	Relative weightage	Loc A	Loc B	Loc C
[QUL]	0.0109	0.0109	0.0061	0.0036
[ALF]	0.0219	0.0122	0.0219	0.0073
[ATT]	0.0109	0.0109	0.0036	0.0012
[MOT]	0.0109	0.0109	0.0012	0.0012
[UIN]	0.0175	0.0175	0.007	0.007
[UNR]	0.0066	0.0033	0.0033	0.0066
[PRD]	0.0175	0.0175	0.0131	0.0109
[COL]	0.0219	0.0219	0.0055	0.0088
[CCA]	0.0219	0.0156	0.0094	0.0219
[CLG]	0.0109	0.0047	0.0066	0.0109
[QLL]	0.0088	0.0088	0.0063	0.0038
[CUL]	0.0109	0.0109	0.0061	0.0036
[TSS]	0.0219	0.0219	0.0094	0.0094
[TES]	0.0175	0.0175	0.0058	0.0019
[UTL]	0.0219	0.0219	0.0073	0.0024
[BSS]	0.0175	0.0175	0.0097	0.0019
[LOP]	0.0088	0.0039	0.0088	0.0029
[AVA]	0.0131	0.0131	0.0066	0.0046
[QUS]	0.0175	0.0175	0.0125	0.0075
[RLS]	0.0088	0.0088	0.0049	0.0029
[FLS]	0.0219	0.0156	0.0219	0.0219
[CIS]	0.0219	0.0219	0.0122	0.017
[RES]	0.0088	0.0088	0.0063	0.0044
[PRS]	0.0219	0.0219	0.0109	0.0055
[SIM]	0.0219	0.0091	0.0164	0.0219
[PXK]	0.0219	0.0219	0.0109	0.0044
[POT]	0.0175	0.0175	0.0088	0.0088
[GRP]	0.0175	0.0175	0.0105	0.0105
[REP]	0.0088	0.0088	0.0049	0.0029
[TYP]	0.0219	0.0156	0.0219	0.0219
[TAT]	0.0175	0.0044	0.0117	0.0175
[CUD]	0.0131	0.0131	0.0079	0.0039
[TAR]	0.0088	0.0088	0.0044	0.0025
[INN]	0.0175	0.007	0.0117	0.0175
[BUC]	0.0219	0.0219	0.0156	0.0094
[COB]	0.0219	0.0219	0.0131	0.0094

[INC]	0.0066	0.0053	0.0066	0.0066
[GGG]	0.0175	0.0175	0.007	0.0053
[STC]	0.0219	0.0156	0.0219	0.0094
[TRP]	0.0153	0.0153	0.0109	0.0066
[GSA]	0.0153	0.0153	0.0109	0.0022
[ITR]	0.0153	0.0153	0.0085	0.0051
[CLL]	0.0153	0.0153	0.0051	0.0085
[INL]	0.0153	0.0066	0.0109	0.0153
[ENR]	0.0131	0.0056	0.0094	0.0131
[IRL]	0.0131	0.0131	0.0094	0.0056
[LES]	0.0153	0.0153	0.0109	0.0066
[CIR]	0.0153	0.0085	0.0153	0.0119
[IER]	0.0088	0.0088	0.0029	0.001
[RJM]	0.0088	0.0088	0.0088	0.0038
[RCE]	0.0066	0.0033	0.0049	0.0066
[LAB]	0.0109	0.0109	0.0055	0.0088
[LAN]	0.0219	0.0219	0.0118	0.0085
[ILC]	0.0197	0.0197	0.0118	0.0089
[OLC]	0.0197	0.0197	0.0098	0.0066
[OPE]	0.0131	0.0088	0.0105	0.0131
[CNL]	0.0109	0.0044	0.0088	0.0109
[UTC]	0.0219	0.0219	0.0156	0.0122
[AFE]	0.0219	0.0219	0.0073	0.0024
[PHC]	0.0175	0.0175	0.0058	0.0019
[PCF]	0.0175	0.0044	0.0088	0.0175
[LCC]	0.0109	0.0109	0.0055	0.0055
[PRR]	0.0131	0.0131	0.0033	0.0022
[LOS]	0.0153	0.0153	0.0077	0.0038
	1.000	**0.8629**	**0.5998**	**0.5096**

The most desirable alternative is location A

Table 3.7: Aggregated indices for the alternatives

Significant category analysis											Total performance analysis
	W	S	I	V	M	E	G	L	C	P	
Loc A	0.865	0.832	0.944	0.945	0.854	0.787	0.907	0.764	0.909	0.864	**0.8629**
Loc B	0.584	0.456	0.468	0.661	0.475	0.681	0.770	0.695	0.625	0.399	**0.5998**
Loc C	0.393	0.659	0.190	0.560	0.409	0.641	0.343	0.649	0.584	0.346	**0.5096**

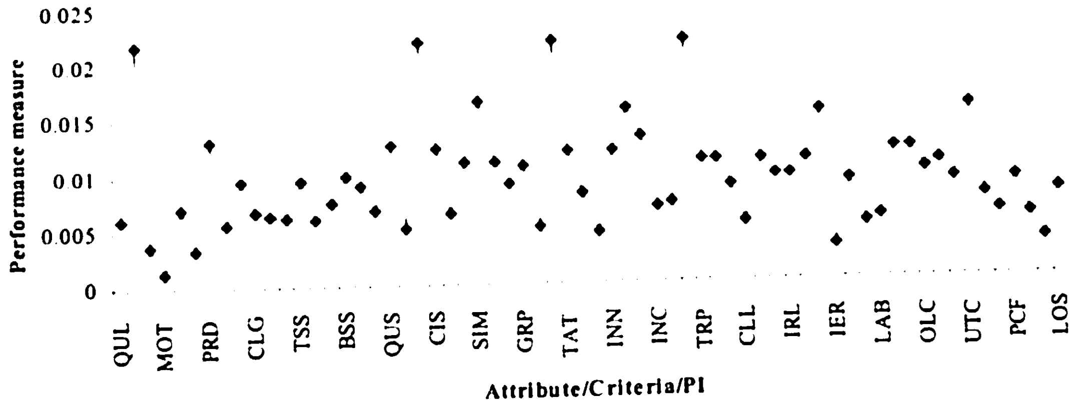

Figure 3.1: Partial performance measure for location A

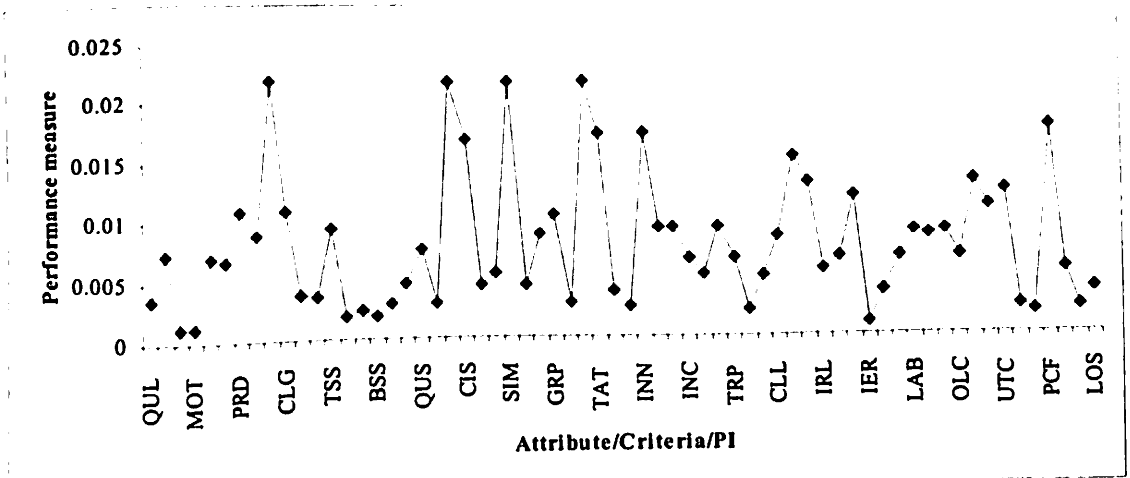

Figure 3.2: Partial performance measure for location B

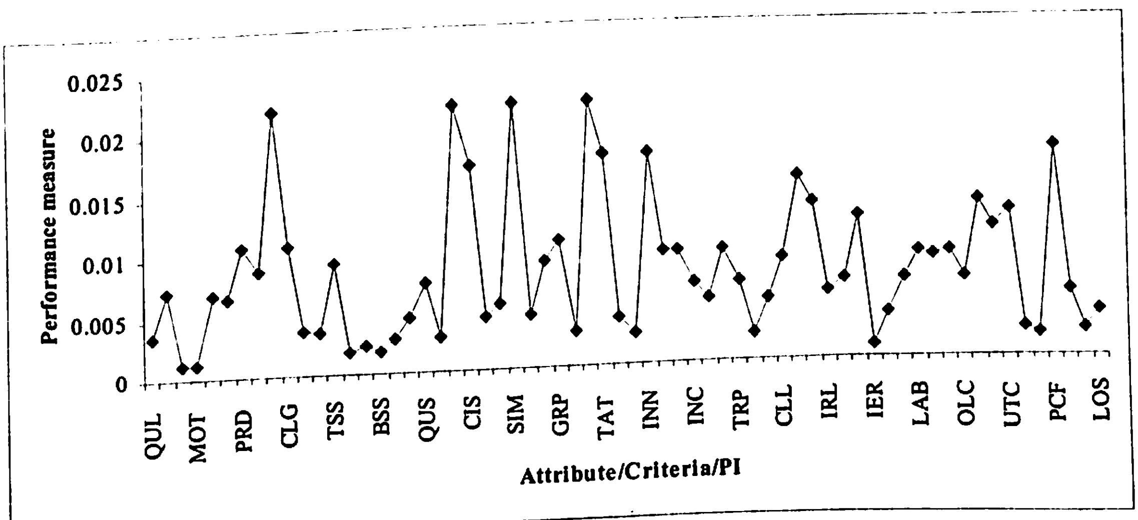

Figure 3.3: Partial performance measure for location C

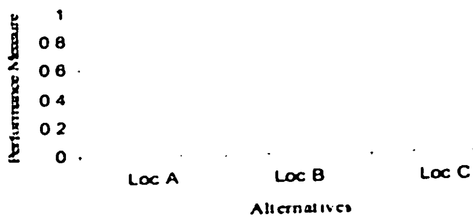

Figure 3.4: Significant category analysis based on workforce (W)

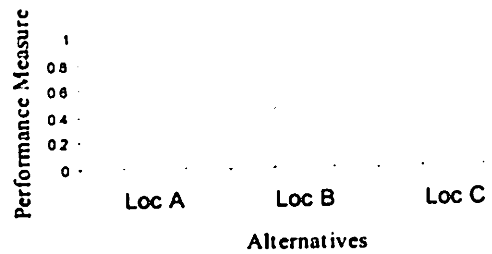

Figure 3.5: Significant category analysis based on social and culture (S)

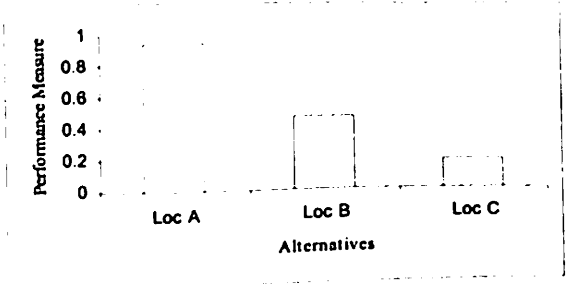

Figure 3.6: Significant category analysis based on infrastructure (I)

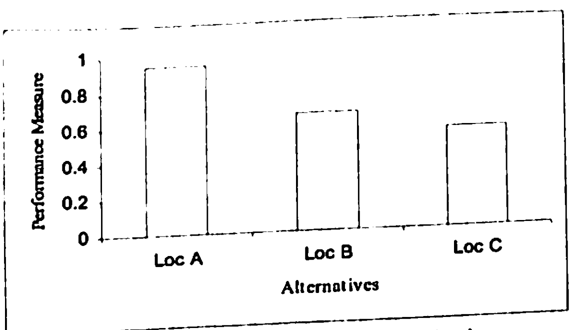

Figure 3.7: Significant category analysis based on suppliers (V)

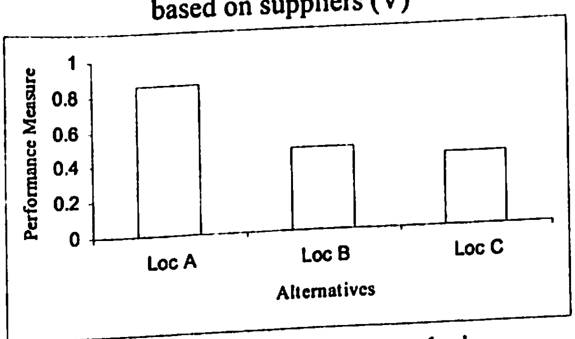

Figure 3.8: Significant category analysis based on markets and customers (M)

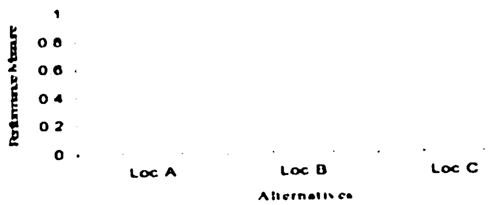

Figure 3.9: Significant category analysis based on economy (E)

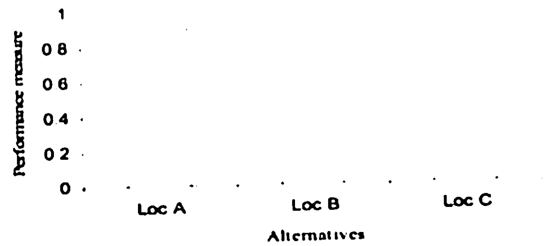

Figure 3.10: Significant category analysis based on government and policies (G)

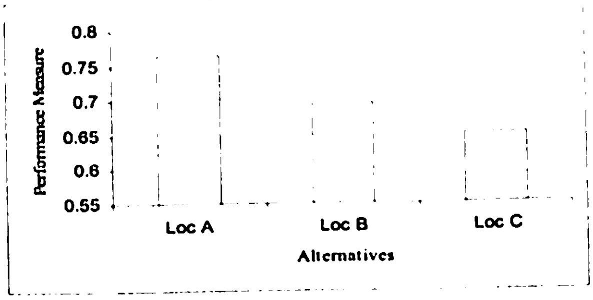

Figure 3.11: Significant category analysis based on legal and regulatory (L)

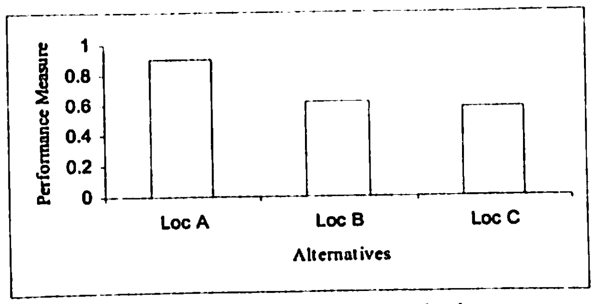

Figure 3.12: Significant category analysis based on cost (C)

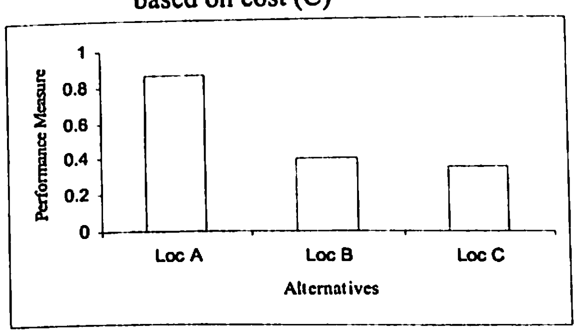

Figure 3.13: Significant category analysis based on characteristics of location specific (P)

3.2.1.2 Validation

The decision support system i.e. performance value analysis model is evaluated by the empirical approach. The approach is to test a representative set of selected test problems. The decision support system facilitates easy verification for the correctness of the performance value analysis by an expert, based on a comparison with his decision. For a representative set of input conditions, the correctness of the system was verified through a comparison of decisions obtained from performance value analysis model and the decisions of the expert and they are found to be identical.

3.2.2 Development of decision support system framework for facilities location

A decision support system framework is developed for selection of facilities location in competitive supply chain, which consists of four phases and it is shown in figure 3.14. Each phase is discussed below.

Supply chain strategy (Phase I): The objective of the first phase is to define the supply chain strategy of the organization. The supply chain strategy specifies what capabilities the supply chain network must have to support a firm's competitive strategy. Phase I starts with clear definition of competitive strategy (i.e. the set of customer needs that the supply chain aims to satisfy) of the organization. Then internal constraints within the organization are found out and one has to forecast whether the competition is global or local. So based on competitive strategy, internal constraints and analysing the competition, the supply chain strategy of the organization should be determined.

Selection of feasible locations (Phase II): The objective of second phase is to select a set of desirable locations where facilities are to be located. The set of desirable locations should be larger than the desired number of facilities to be set up so that a precise selection may be made in phase III. The selection of desirable locations is based on location factors.

Analysis of feasible locations (Phase III): During the third phase of the process, the feasible locations are analyzed. The analysis is: qualitative and cost. In qualitative analysis, the feasible locations are compared based on location factors and in cost analysis, the impact of each feasible location on total cost is evaluated.

Rank the feasible locations (Phase IV): During the fourth phase of the process, the outcomes of the qualitative and cost analysis are combined in order to calculate benefit/cost-ratios for each feasible location. Rank the feasible locations based on benefit/cost-ratios.

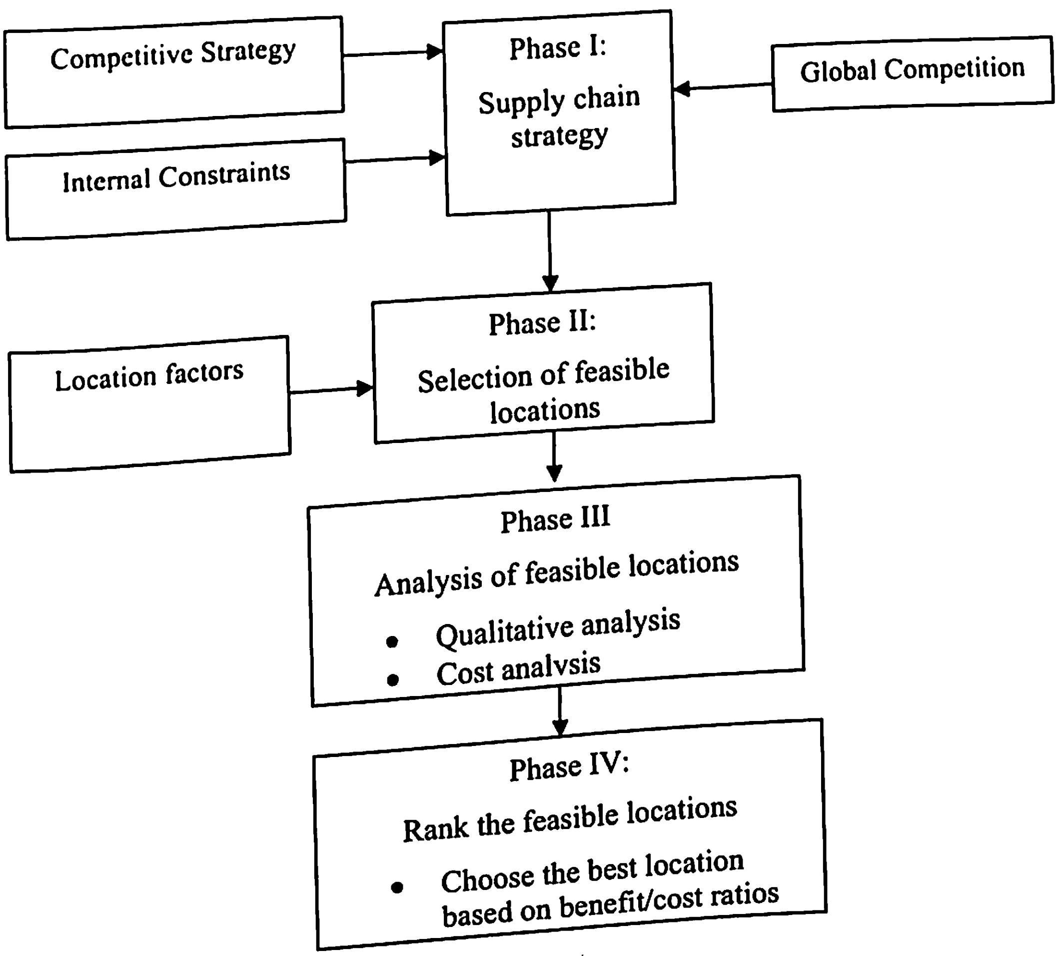

Figure 3.14: A decision support system framework for selection of facilities location

The use of the presented decision support system framework for selection of facilities location in competitive supply chain is demonstrated with an illustrative example. Company X is involved in an automotive production. Most of the products are world-class and supply chain is a key competitive factor in the business. The logistics executives now face the problem to develop the competitive supply chain. Based on preliminary analysis, the logistics executives identified three possible feasible locations for facilities i.e. location A, location B and location C during second phase of decision support system framework. The key phases, in the decision support system framework are the third and fourth. The third and fourth phases of decision support system framework for selection of facilities location are discussed below.

3.2.2.1 Development of analytical hierarchy process for qualitative analysis

Analytical hierarchy process (AHP) was developed in 1972 as a practical approach in solving relatively complex problems (Satty, 1980). It is used for multi-criteria problems in a number of application domains (Roger, 1987; Partovi, 1994; Satty, 2000; Kodali and Chandra, 2001). The general approach of the AHP is to decompose the problem and make pair-wise comparison of all elements on a given level with the related elements in the level just above to which it belong. A highly user-friendly computer model is developed which assists the user in evaluating his/her choices. The schematic of AHP for qualitative analysis for feasible locations is shown in figure 3.15. A thorough analysis of the problem is required along with the identification of the important attributes/factors/criteria involved. The selection of attributes/factors/criteria has been determined through literature survey and discussions held with experts. The attributes and sub-attributes used in the AHP for qualitative analysis for feasible locations are as follows:

Workforce [WRF]

- Quality [QUL]
- Availability [ALF]
- Attitude [ATT]
- Motivation [MOT]
- Unions [UIN]
- Unemployment rate [UNR]
- Productivity [PRD]

Social and culture [SOC]

- Cost of living [COL]
- Community cooperation and attitude [CCA]
- Communicative language [CLG]
- Quality of life [QLL]
- Culture [CUL]

Infrastructure [INF]

- Transport systems [TSS]
- Telecommunication systems [TES]
- Utilities (energy and water) [UTL]
- Business/support services (IT, financial, legal) [BSS]
- Logistics providers [LOP]

Suppliers [SUP]

- Availability [AVA]
- Quality [QUS]
- Reliability of supply process system [RLS]
- Flexible [FLS]
- Continuous improvement commitment [CIS]
- Responsiveness [RES]
- Proximity [PRS]

Markets and Customers	[MAC]
➢ Proximity	[PXK]
➢ Size of market	[SIM]
➢ Population trends	[POT]
➢ Growth potential	[GRP]
➢ Receptivity	[REP]
Economy	[ECO]
➢ Type	[TYP]
➢ Tax structure and tax incentives	[TAT]
➢ Custom duties	[CUD]
➢ Tariffs	[TAR]
➢ Inflation	[INN]
➢ Business climate	[BUC]
➢ Country's debt	[COB]
➢ Interest rates/exchange controls	[INC]
➢ GDP/GNP growth	[GGG]
Government and policies	[GAP]
➢ Stability and consistency	[STC]
➢ Transparency	[TRP]
➢ Government support and attitude	[GSA]
➢ International relations	[ITR]
Legal and regulatory	[LAR]
➢ Compensation laws	[CLL]
➢ Insurance laws	[INL]
➢ Environmental regulations	[ENR]

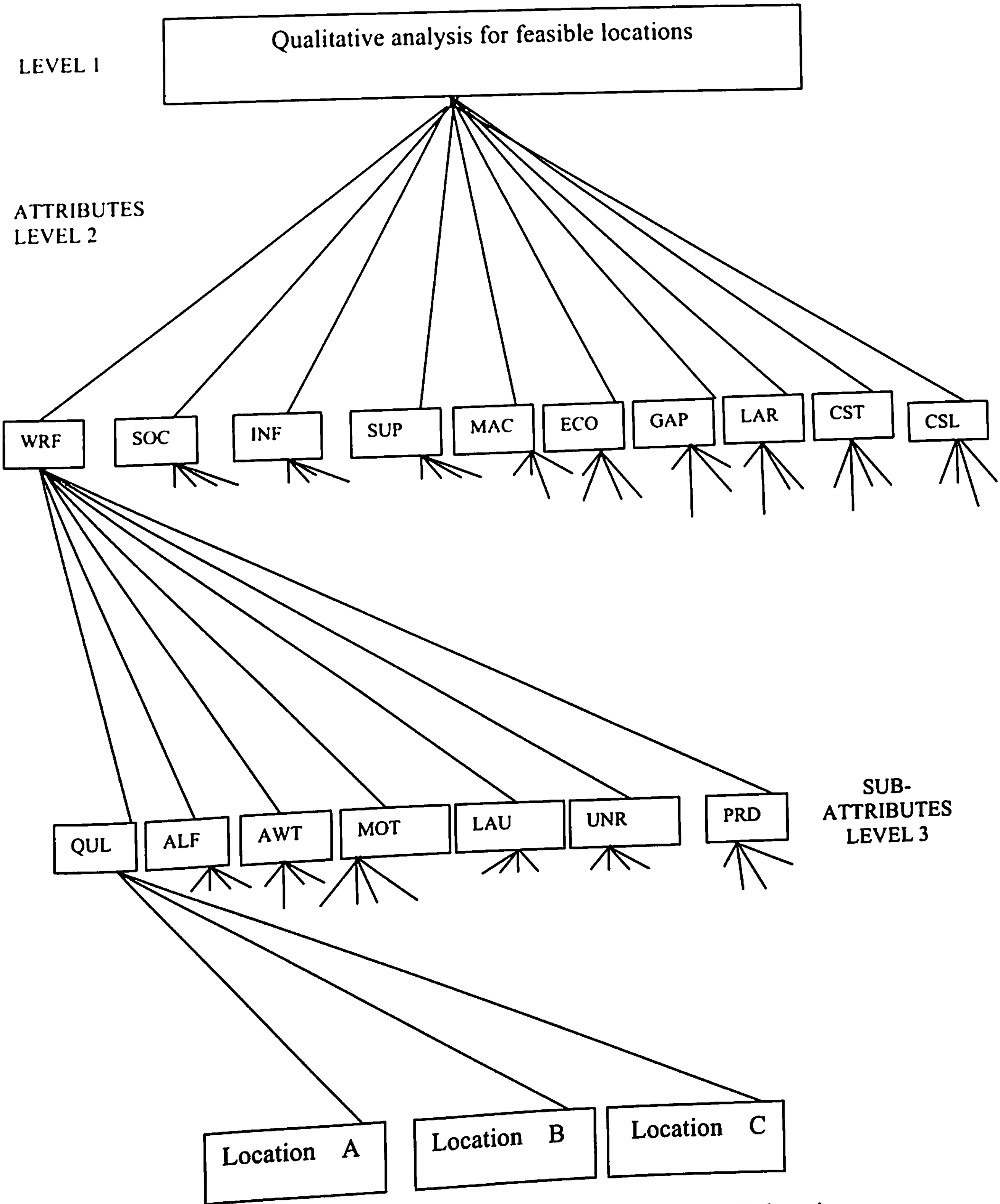

Figure 3.15: Schematic of AHP for qualitative analysis for feasible locations

- Industrial relation laws [IRL]
- Legal systems [LES]
- Corporate investment regulations [CIR]
- Import/Export regulations [IER]
- Regulations concerning joint ventures and mergers [RJM]
- Regulations on transfer of earnings rate out of country [RCE]

Costs [CST]

- Labour [LAB]
- Land [LAN]
- Inbound logistics [ILC]
- Outbound logistics [OLC]
- Operating [OPE]
- Construction/leasing [CNL]
- Utilities [UTC]

Characteristics of location specific [CLS]

- Availability of space for the future expansion [AFE]
- Physical conditions [PHC]
- Proximity to parent company's facilities [PCF]
- Location of competitors [LCC]
- Proximity to resources [PRR]
- Location of suppliers [LOS]

3.2.2.1.1 Methodology

For the qualitative analysis for feasible locations, the judgments based on observations are fed into AHP for each criterion and sub-criterion of all level of hierarchy. Pair-wise comparisons of criterion at each level are done on a scale relative importance, 1 reflecting equal weightage and 9 reflecting absolute importance (Satty, 2000; Crowe *et al.*, 1998; Hafeez *et al.*, 2002).

The steps to follow in using the AHP (Satty, 1980) are:

Step 1. Define the problem and determine the objective.

Step 2. Structure the hierarchy from the top through the intermediate levels to the lowest level (see figure 3.15).

Step 3. Construct a set of pair-wise comparison matrices for each of the lower levels. An element in the higher level is said to be a governing element for those in the lower level, since it contributes to it or affects it. The elements in the lower level are then compared to each other based on their effect on the governing element above. This yields a square matrix of judgments. The pair-wise comparisons are done in terms of which an element dominates another. These judgments are then expressed as integers. If element A dominates over element B, then the whole number integer is entered in row A, column B and reciprocal is entered in row B, column A. If the elements being compared are equal, a one is assigned to both positions. Table 3.8 shows the pair-wise comparison matrix for level 2 criteria.

Step 4. There are n (n-1)/2 judgments required to develop the set of matrices in step 3 (reciprocals are automatically assigned in each pair-wise comparisons).

Step 5. Having done all the pair-wise comparisons and entered the data, the consistency is determined using the eigen value. To do so, normalize the column of numbers by dividing each entry by the sum of all entries. Then sum each row of the normalized values and take the average. This provides Principal Vector (PV). Table 3.9 illustrates the normalized comparison matrix. The check of the consistency of judgments is as follows:

Let the pair-wise comparison matrix be denoted M1 and principal vector be denoted M2.Then define M3 = M1*M2 and M4 = M3/M2.

λ_{max} = average of the elements of M4.

Consistency Index (CI) = (λ_{max} - *N*) / *N* – 1

Consistency Ratio (CR) = CI/RI corresponding to *N*

Where RI: Random Consistency Index and *N*: Number of elements

Random index table

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

If CR is less than 10%, judgments are considered consistent. And if CR is greater than 10%, the quality of judgments should be improved to have CR less than or equal to 10%.

Step 6. Steps 3-5 are performed to have relative importance of each attribute for all levels and clusters in the hierarchy. Table 3.10 illustrates the sub-criteria analysis of attribute, 'Workforce'.

Step 7. The alternative analysis for the lowest level of sub-attribute to be carried out in the similar manner as above. Table 3.11 illustrates the alternative analysis of 'Labour'. The remaining alternative analysis is to be carried out.

Step 8. The desirability index for each alternative is calculated by multiplying each value in "weight of sub-attribute" column by the respective value of "attribute weight" column, then multiplying by the value for each respective alternative and summing the results.

3.2.2.1.2 Validation

Highly user-friendly software, the multi-attribute decision model i.e. AHP is developed in VC++ to aid the user for pair-wise comparison of the attributes as well as for the alternatives and for analyzing the user inputs. The attributes are compared with each other in a pair-wise comparison with respect to the case situation discussed in table 3.2. Table 3.8 shows the pair-wise comparison matrix for level 2 criteria and its normalized comparison matrix is illustrated in table 3.9. The consistency of judgments is also checked. The sub-attribute analysis of attribute, 'Workforce' is shown in table 3.10 and also the alternative analysis for 'Labour' is shown in table 3.11. From the analysis, it is clear that location A is the best under the circumstances of the developed case situation (see table 3.12-14). The reliability of the judgments supplied by the user can be estimated from the graphs (figure 3.16-18) that are generated for each alternative/feasible location and its corresponding deciding criteria.

Table 3.8: Criteria pair-wise comparison matrix (level 2)

	WRF	SOC	INF	SUP	MAC	ECO	GAP	LAR	CST	CSL
WRF	1	1/2	1/2	1	1/3	1/3	1/3	1/3	1/5	1/4
SOC	2	1	1/2	1/2	1/3	1/3	1/3	1/3	1/5	1/4
INF	2	2	1	1	2	1	1	1	1/2	1/2
SUP	1	2	1	1	1	1	1	1	1/2	1/2
MAC	3	3	1/2	1	1	1	1	1	1/2	1/3
ECO	3	3	1	1	1	1	1	1	1/2	1/3
GAP	3	3	1	1	1	1	1	1	1/2	1/3
LAR	3	3	1	1	1	1	1	1	1/2	1/3
CST	5	5	2	2	2	2	2	2	1	2
LSC	4	4	2	2	3	3	3	3	1/2	1

Table 3.9: Criteria pair-wise comparison matrix (level 2) normalized

	WRF	SOC	INF	SUP	MAC	ECO	GAP	LAR	CST	LSC	SUM	PV
WRF	0.037	0.019	0.048	0.087	0.026	0.029	0.029	0.029	0.041	0.043	0.386	0.039
SOC	0.074	0.038	0.048	0.043	0.026	0.029	0.029	0.029	0.041	0.043	0.399	0.040
INF	0.074	0.075	0.095	0.087	0.158	0.086	0.086	0.086	0.102	0.086	0.935	0.093
SUP	0.037	0.075	0.095	0.087	0.079	0.086	0.086	0.086	0.102	0.086	0.819	0.082
MAC	0.111	0.113	0.048	0.087	0.079	0.086	0.086	0.086	0.102	0.057	0.854	0.085
ECO	0.111	0.113	0.095	0.087	0.079	0.086	0.086	0.086	0.102	0.057	0.902	0.090
GAP	0.111	0.113	0.095	0.087	0.079	0.086	0.086	0.086	0.102	0.057	0.902	0.090
LAR	0.111	0.113	0.095	0.087	0.079	0.086	0.086	0.086	0.102	0.057	0.902	0.090
CST	0.185	0.189	0.190	0.174	0.158	0.171	0.171	0.171	0.204	0.343	1.957	0.196
CSL	0.148	0.151	0.190	0.174	0.237	0.257	0.257	0.257	0.102	0.171	1.945	0.195
Consistency Index (CI) = 0.0364 Consistency Ratio (CR) = 0.0246												

Table 3.10: Workforce sub-criteria analysis (Level 3)

	QUL	ALF	AWT	MOT	LAU	UNR	PRD
QUL	1	1/2	2	2	1/2	3	1/2
ALF	2	1	5	4	2	6	1
AWT	1/2	1/5	1	1	1/4	2	1/3
MOT	1/2	1/4	1	1	1/2	4	1/4
LAU	2	1/2	4	2	1	5	1
UNR	1/3	1/6	1/2	1/4	1/5	1	1/7
PRD	2	1	3	4	1	7	1
SUM	8.333	3.617	16.500	14.250	5.450	28.000	4.226

Table 3.11: Alternative analysis for Labour (LAB)

	Location A	Location B	Location C
Location A	1	2	3
Location B	1/2	1	2
Location C	1/3	1/2	1
SUM	1.8333	3.500	6.000

Table 3.12: Weightages of attributes for alternatives

Subcr	L3-wt	L2-wt	LOC A	LOC B	LOC C
QUL	0.12	0.039	0.539	0.164	0.297
ALF	0.274	0.039	0.539	0.297	0.164
ATT	0.063	0.039	0.633	0.192	0.175
MOT	0.079	0.039	0.525	0.142	0.334
UIN	0.194	0.039	0.557	0.32	0.123
UNR	0.034	0.039	0.277	0.595	0.129

PRD	0.236	0.039	0.623	0.239	0.137
COL	0.343	0.04	0.732	0.13	0.138
CCA	0.343	0.04	0.277	0.129	0.595
CLG	0.108	0.04	0.309	0.581	0.11
QUL	0.097	0.04	0.589	0.252	0.159
CUL	0.108	0.04	0.277	0.129	0.595
TSS	0.29	0.093	0.292	0.615	0.093
TES	0.153	0.093	0.106	0.26	0.633
UTL	0.333	0.093	0.192	0.175	0.633
BSS	0.142	0.093	0.685	0.221	0.093
LOP	0.082	0.093	0.309	0.581	0.11
AVA	0.19	0.082	0.681	0.201	0.118
QUS	0.064	0.082	0.62	0.156	0.224
RLS	0.072	0.082	0.623	0.239	0.137
FLS	0.156	0.082	0.292	0.615	0.093
CIS	0.226	0.082	0.633	0.26	0.106
RES	0.075	0.082	0.548	0.211	0.241
PXS	0.218	0.082	0.263	0.11	0.627
PXK	0.301	0.085	0.557	0.32	0.123
SIM	0.361	0.085	0.416	0.458	0.126
POT	0.077	0.085	0.557	0.32	0.123
GRP	0.191	0.085	0.32	0.557	0.123
REP	0.07	0.085	0.539	0.297	0.164
TYP	0.219	0.09	0.309	0.581	0.11
TAT	0.079	0.09	0.633	0.106	0.26
CUD	0.044	0.09	0.5	0.25	0.25
TAR	0.041	0.09	0.557	0.32	0.123
INN	0.084	0.09	0.655	0.211	0.133
BUC	0.222	0.09	0.539	0.297	0.164
COB	0.204	0.09	0.539	0.164	0.297
INC	0.037	0.09	0.623	0.239	0.137
GGG	0.069	0.09	0.539	0.164	0.297
STC	0.32	0.09	0.5	0.25	0.25
TRP	0.144	0.09	0.556	0.09	0.354
GSA	0.144	0.09	0.548	0.211	0.241
ITR	0.391	0.09	0.633	0.192	0.175
CLL	0.187	0.09	0.619	0.096	0.284
INL	0.187	0.09	0.216	0.681	0.103
ENR	0.064	0.09	0.557	0.32	0.123
IRL	0.059	0.09	0.589	0.252	0.159
LES	0.187	0.09	0.137	0.239	0.623
CIL	0.187	0.09	0.297	0.164	0.539
IER	0.051	0.09	0.595	0.129	0.277

RJM	0.039	0.09	0.315	0.602	0.082
RCE	0.04	0.09	0.557	0.123	0.32
LAB	0.212	0.196	0.557	0.123	0.32
LAN	0.212	0.196	0.297	0.539	0.164
ILC	0.118	0.196	0.702	0.227	0.072
OLC	0.07	0.196	0.639	0.274	0.087
OPE	0.103	0.196	0.297	0.539	0.164
CNL	0.048	0.196	0.627	0.292	0.081
UTC	0.238	0.196	0.737	0.186	0.077
AFE	0.244	0.195	0.568	0.334	0.098
PHC	0.071	0.195	0.557	0.32	0.123
PCF	0.08	0.195	0.539	0.297	0.164
LCC	0.059	0.195	0.648	0.23	0.122
PRS	0.268	0.195	0.525	0.142	0.334
LOS	0.278	0.195	0.539	0.297	0.164

Table 3.13: Data summary

Subcr	LOC A	LOC B	LOC C
QUL	0.002	0.001	0.001
ALF	0.006	0.003	0.002
ATT	0.002	0	0
MOT	0.002	0	0.001
UIN	0.004	0.002	0.001
UNR	0	0.001	0
PRD	0.006	0.002	0.001
COL	0.01	0.002	0.002
CCA	0.004	0.002	0.008
CLG	0.001	0.003	0
QUL	0.002	0.001	0.001
CUL	0.001	0.001	0.003
TSS	0.008	0.017	0.003
TES	0.002	0.004	0.009
UTL	0.006	0.005	0.02
BSS	0.009	0.003	0.001
LOP	0.002	0.004	0.001
AVA	0.011	0.003	0.002
QUS	0.003	0.001	0.001
RLS	0.004	0.001	0.001
FLS	0.004	0.008	0.001
CIS	0.012	0.005	0.002
RES	0.003	0.001	0.001
PXS	0.005	0.002	0.011
PXK	0.014	0.008	0.003

SIM	0.013	0.014	0.004
POT	0.004	0.002	0.001
GRP	0.005	0.009	0.002
REP	0.003	0.002	0.001
TYP	0.006	0.011	0.002
TAT	0.005	0.001	0.002
CUD	0.002	0.001	0.001
TAR	0.002	0.001	0
INN	0.005	0.002	0.001
BUC	0.011	0.006	0.003
COB	0.01	0.003	0.005
INC	0.002	0.001	0
GGG	0.003	0.001	0.002
STC	0.014	0.007	0.007
TRP	0.007	0.001	0.005
GSA	0.007	0.003	0.003
ITR	0.022	0.007	0.006
CLL	0.01	0.002	0.005
INL	0.004	0.011	0.002
ENR	0.003	0.002	0.001
IRL	0.003	0.001	0.001
LES	0.002	0.004	0.01
CIL	0.005	0.003	0.009
IER	0.003	0.001	0.001
RJM	0.001	0.002	0
RCE	0.002	0	0.001
LAB	0.023	0.005	0.013
LAN	0.012	0.022	0.007
ILC	0.016	0.005	0.002
OLC	0.009	0.004	0.001
OPE	0.006	0.011	0.003
CNL	0.006	0.003	0.001
UTC	0.034	0.009	0.004
AFE	0.027	0.016	0.005
PHC	0.008	0.004	0.002
PCF	0.008	0.005	0.003
LCC	0.007	0.003	0.001
PRS	0.027	0.007	0.017
LOS	0.029	0.016	0.009

Table 3.14: Decision index for desirability of each alternative/ feasible location

Decision index of Location A: 0.4913
Decision index of Location B: 0.2881
Decision index of Location C: 0.2205

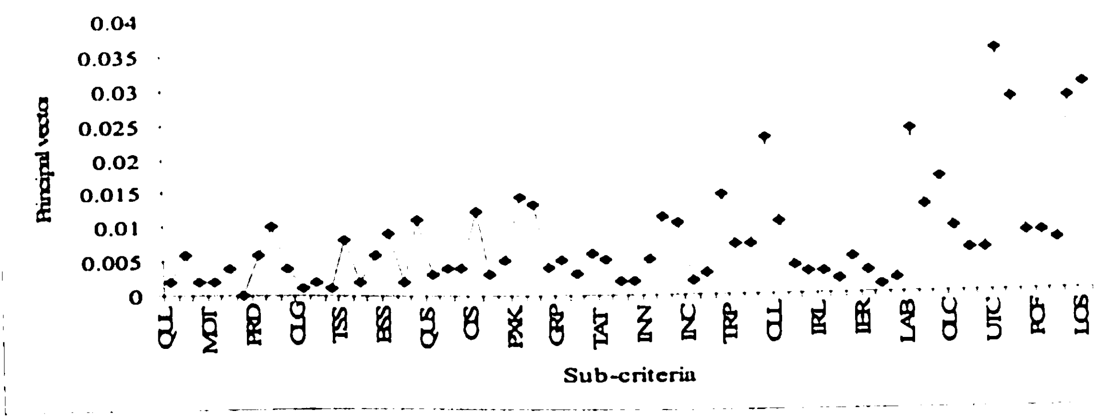

Figure 3.16: Data summary graph for location A

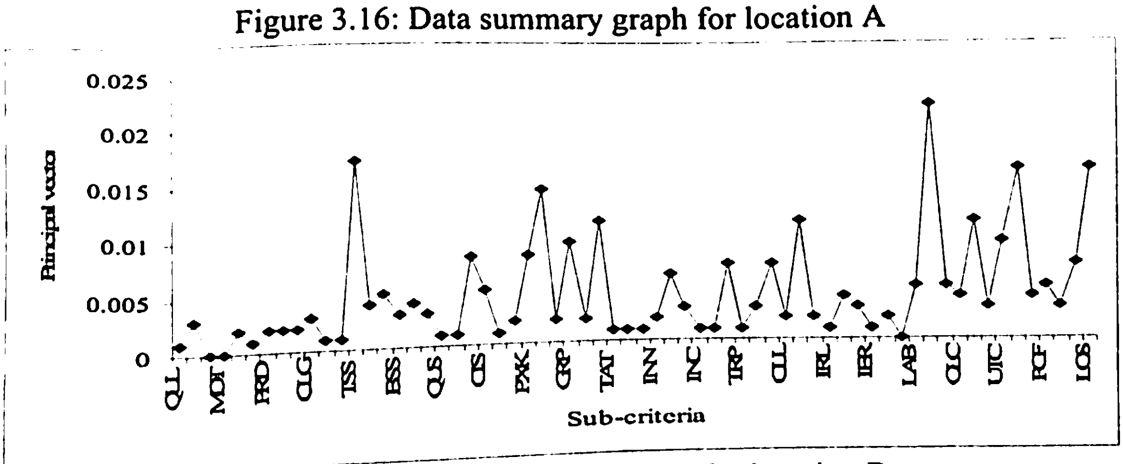

Figure 3.17: Data summary graph for location B

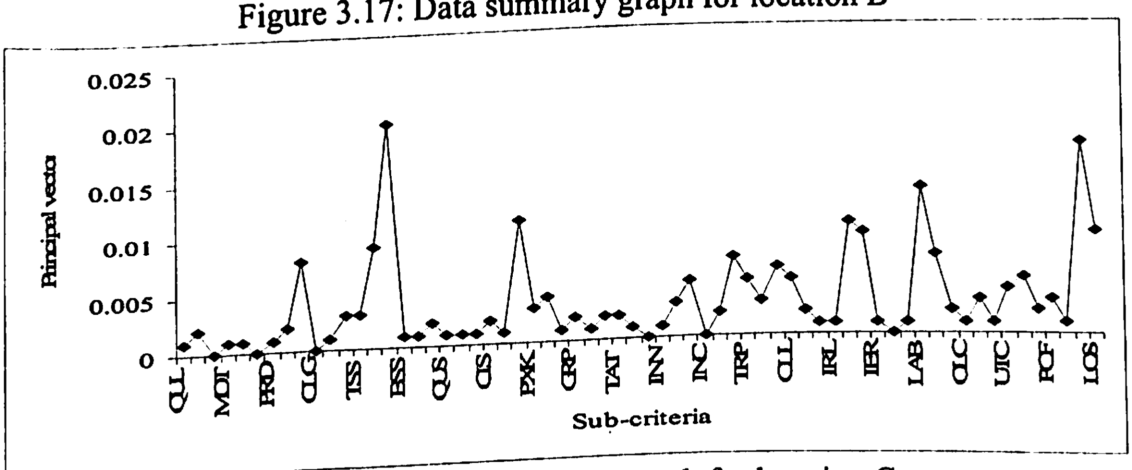

Figure 3.18: Data summary graph for location C

3.2.2.2 Cost analysis

Total cost analysis is the foundation of the competitive supply chain. The objective of the total cost analysis is to minimise the cost of procurement, production and distribution along the supply chain while achieving customer service level requirements. In the selection of facilities location in competitive supply chain, the purpose of the cost analysis is to examine the effect of each feasible location on the total supply chain costs of a company. The outcome of the cost analysis is illustrated in table 3.15.

Table 3.15: The cost impact of the feasible locations

Feasible locations	Total supply chain cost ($ 100 million)
Location A	1.75
Location B	2.50
Location C	1.85

3.2.2.3 Rank the feasible locations

The outcomes of the qualitative analysis and the cost analysis are combined by calculating the benefit/cost-ratio for each feasible location. The results of the final phase of the selection of facilities locations or the benefit/cost ratios of feasible locations are presented in table 3.16. The "location A" had the highest overall priority in the qualitative analysis and its impact on the total supply chain costs is also less compared to the other alternatives. Therefore the overall rank for "location A" is first. Although the qualitative analysis priority of "location B" is more in comparison to "location C", but it was not enough to compensate for the total supply chain costs and thus the benefit/cost-ratio of location B is less than that of location C. Therefore, the overall rank of "location B" is third and "location C" is second.

Table 3.16: The benefit/cost-ratios of the feasible locations

Feasible locations	Qualitative analysis (priority)	Cost analysis ($ 100 million)	Benefit/cost-ratio	Rank
Location A	0.4913	1.75	0.281	1
Location B	0.2881	2.50	0.11524	3
Location C	0.2205	1.85	0.119	2

3.3 Development of decision support system framework for selection of capacity

The facilities location i.e. plants or warehouses is an inevitable strategic decision for most organizations as it has a direct bearing on the cost of supplying commodities to customers. Transportation costs often form a major portion of the price (or cost) of goods. Equally important to the organizations are the fixed costs involved in opening and operating a plant at any given location. Such location problems have been widely studied in the literature under the names of plant, warehouse, or facility location problems (Sridharan, 1995). The capacitated plant location problem (CPLP) is a classical combinatorial optimisation problem (Bramel and Simchi, 1997). It amounts to optimally locate 'p' capacitated facilities (warehouses, plants, polling stations, etc.) in such a way that the sum of the fixed costs associated with opening the facilities and the total costs of supplying customers is minimized. If no fixed costs are associated to the potential facilities, then the CPLP is called the capacitated 'p-median' problem (CPMP). Exact algorithms have been developed by Christo and Beasley (1983), Leung and Magnanti (1989), whereas heuristics have been investigated by Beasley (1988), Christo and Beasley (1983), Geoffrion and McBride (1978), Guinard and Kim (1987), Jacobsen (1983) and Khumawala (1974). Ghiani *et al.* (2002) solved the capacitated plant location problem (CPLP) with multiple facilities in the same site, a special case of the classical CPLP where several facilities can be opened in the same site using a novel Lagrangean relaxation and a tailored Lagrangean heuristic that overcome the drawbacks of classical procedures.

It is obvious that capacity decision in the supply chain is a complex, multi-attribute decision problem that must be accomplished within a constrained resource environment. An AHP allows decision maker to find the priority rankings of the potential facilities locations in the supply chain considering the relevant attributes. This priority has to be maximized where as the cost associated due to transportation of raw materials between suppliers and facilities locations, the cost associated due to transportation of finished products between markets and facilities locations and the total cost of facilities locations which depends upon the number of facilities locations and their capacity have to be minimized while taking capacity decision in the supply chain. For this, a hybrid approach is developed which integrates the AHP with a 0-1 integer programming model. Simulated annealing model is used for solving the capacity decision problem in the supply chain. The proposed hybrid approach is based on integrating the AHP and multi-objective programming. The AHP and linear programming have earlier been used together by Korhonen and Wallenius (1990) for formulating a marketing strategy, by Gass (1986) for large-scale personnel planning models, by Olson et. al. (1986) for an export planning model for a developing country and by Korpela and Tuominen (1995), Korpela and Lehmusvaara (1999), Korpela *et al.* (1998, 1999) and Lehmusvaara *et al.*, (1997) for logistics structure. AHP has also been combined with the multi-objective programming methodology of goal programming (GP) by Schniederjans and Garvin (1997), Badri (1999), Kim *et al.*, (1999) and Radcliffe and Schniederjans (2003). Decision support system framework for selection of capacity is shown in figure 3.19. Figure 3.19 depicts the hybrid approach with the involvement of the decision maker at the centre of the process. Decision maker must define the decision hierarchy, define criteria and evaluate the locations against the criteria. The decision maker interacts with the AHP model for evaluation of alternatives. One of the key factors behind broad acceptance of AHP, and a primary reason why it was selected as the lead component of our hybrid approach, is the value AHP places on a decision maker's input and the crucial role these inputs play in the decision making process. AHP is capable of integrating both qualitative and quantitative criteria into the decision making process. Finally, through the pair-wise comparison process, AHP decomposes large, complex decisions and allows the decision maker to focus there attention on each criterion. Once the priorities for each location alternative have been determined, they are incorporated into the optimization component where they represent value coefficients for a linear objective function. The capacity optimization is solved by using simulating annealing algorithm to define the final capacity in the supply chain.

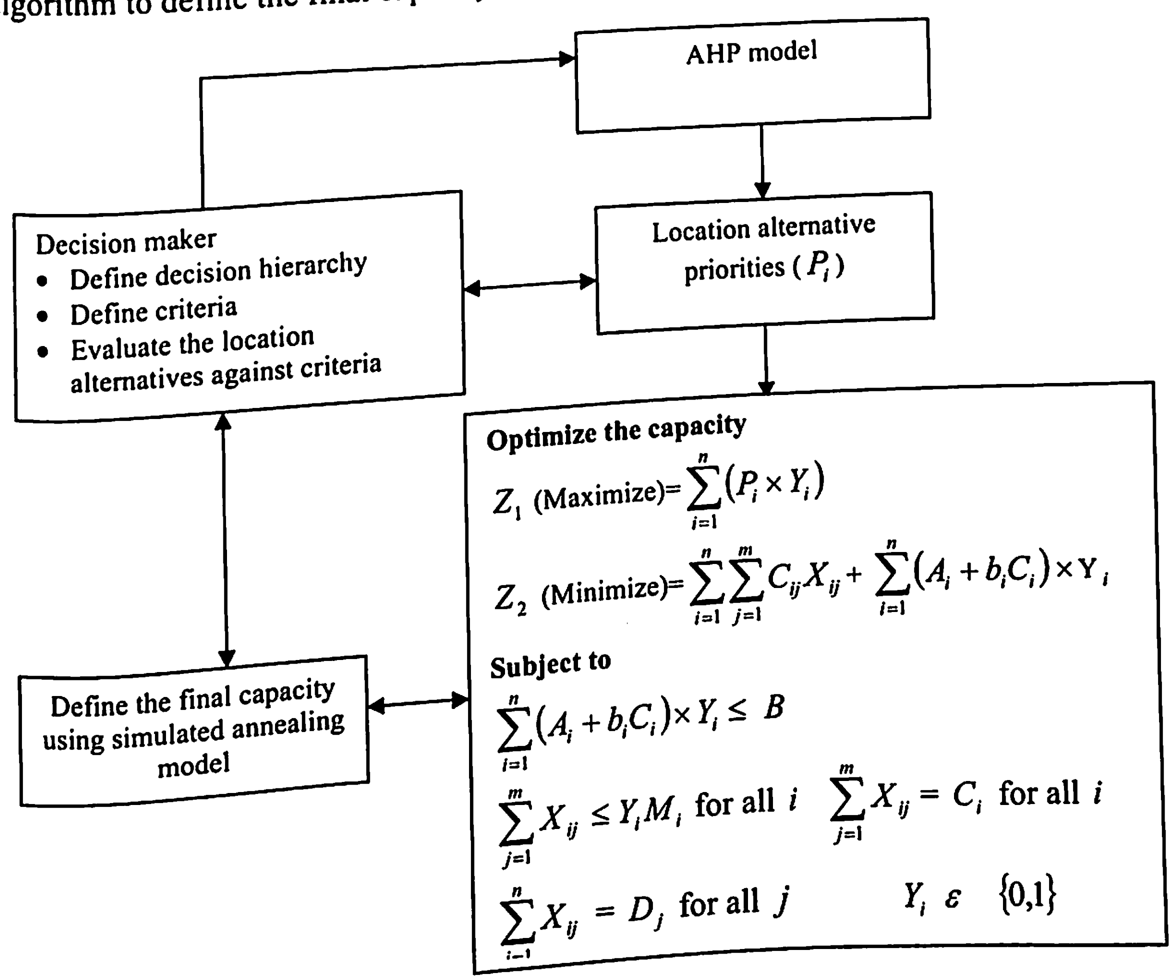

Figure 3.19 Decision support system framework for selection of capacity

3.3.1 Development of AHP for determination of the priority value for alternative locations

The AHP is a multi-criteria decision support methodology introduced by Satty (1980), which has been widely used by both practitioners and researchers in addressing complex decision. It is used for multi-criteria problems in a number of application domains (Roger, 1987; Partovi, 1994; Satty, 2000 and Kodali *et al.*, 2001). The AHP allows decision maker to model a complex problem as a hierarchical structure that shows the relationship between the goal, primary criteria, sub-criteria and alternatives. The general approach of the AHP is to decompose the problem and make pair-wise comparison of all elements on a given level with the related elements in the level just above to which it belong. A thorough analysis of the problem is required along with the identification of the important attributes/factors/criteria involved. The selection of attributes/factors/ criteria has been determined through literature survey and discussions held with experts for determination of the priority value for alternative locations (i.e. n_1, n_2, n_3, n_4, n_5). The schematic of AHP for determination of priority value for alternative locations is shown in figure 3.20. The attributes and sub-attributes used in the AHP for determination of priority value for alternative locations are as follows:

Workforce [WRF]

- Quality [QUL]
- Availability [ALF]
- Attitude [ATT]
- Motivation [MOT]
- Unions [UIN]
- Unemployment rate [UNR]
- Productivity [PRD]

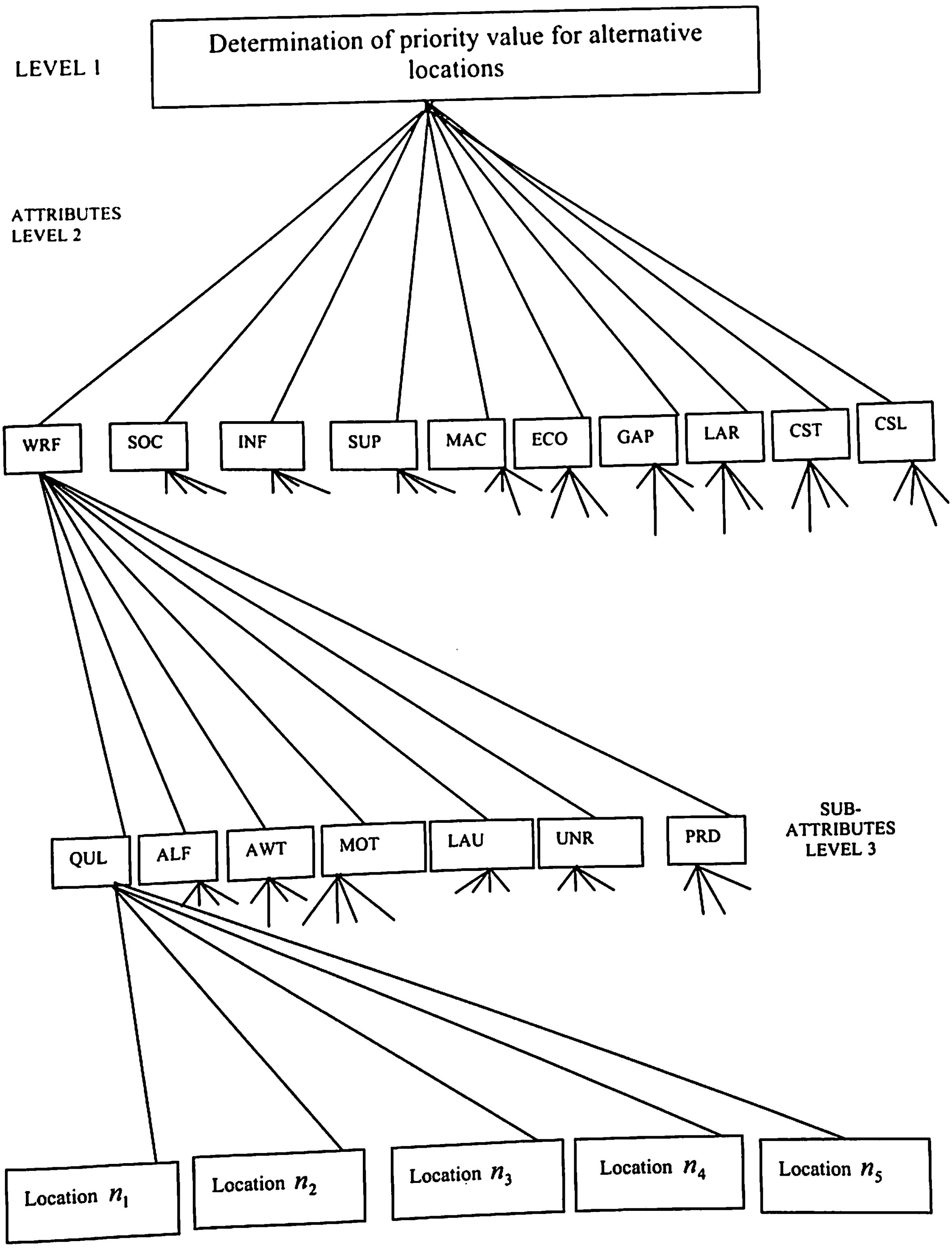

Figure 3.20: Schematic of AHP for determination of priority value for alternative locations

Social and culture	[SOC]
• Cost of living	[COL]
• Community cooperation and attitude	[CCA]
• Communicative language	[CLG]
• Quality of life	[QLL]
• Culture	[CUL]
Infrastructure	[INF]
• Transport systems	[TSS]
• Telecommunication systems	[TES]
• Utilities (energy and water)	[UTL]
• Business/support services (IT, financial, legal)	[BSS]
• Logistics providers	[LOP]
Suppliers	[SUP]
• Availability	[AVA]
• Quality	[QUS]
• Reliability of supply process system	[RLS]
• Flexible	[FLS]
• Continuous improvement commitment	[CIS]
• Responsiveness	[RES]
• Proximity	[PRS]
Markets and Customers	[MAC]
• Proximity	[PXK]
• Size of market	[SIM]
• Population trends	[POT]
• Growth potential	[GRP]
• Receptivity	[REP]

Economy	[ECO]
• Type	[TYP]
• Tax structure and tax incentives	[TAT]
• Custom duties	[CUD]
• Tariffs	[TAR]
• Inflation	[INN]
• Business climate	[BUC]
• Country's debt	[COB]
• Interest rates/exchange controls	[INC]
• GDP/GNP growth	[GGG]
Government and policies	[GAP]
• Stability and consistency	[STC]
• Transparency	[TRP]
• Government support and attitude	[GSA]
• International relations	[ITR]
Legal and regulatory	[LAR]
• Compensation laws	[CLL]
• Insurance laws	[INL]
• Environmental regulations	[ENR]
• Industrial relation laws	[IRL]
• Legal systems	[LES]
• Corporate investment regulations	[CIR]
• Import/Export regulations	[IER]
• Regulations concerning joint ventures and mergers	[RJM]
• Regulations on transfer of earnings rate out of country	[RCE]
Costs	[CST]
• Labour	[LAB]

- Land [LAN]
- Inbound logistics [ILC]
- Outbound logistics [OLC]
- Operating [OPE]
- Construction/leasing [CNL]
- Utilities [UTC]

Characteristics of location specific [CLS]

- Availability of space for the future expansion [AFE]
- Physical conditions [PHC]
- Proximity to parent company's facilities [PCF]
- Location of competitors [LCC]
- Proximity to resources [PRR]
- Location of suppliers [LOS]

For the determination of priority value for alternative locations, the judgments based on observations are fed into AHP for each criterion and sub-criterion of all level of hierarchy. Pair-wise comparisons of criterion at each level are done on a scale relative importance, 1 reflecting equal weightage and 9 reflecting absolute importance (Satty, 2000, Crowe et. al., 1998, Hafeez, 2002). Highly user-friendly software, the multi-attribute decision model i.e. AHP is developed in VC++ to aid the user for pair-wise comparison of the attributes as well as for the alternatives and for analyzing the user inputs. The attributes are compared with each other in a pair-wise comparison with respect to the case situation discussed in table 3.2. The priority value of alternative locations is shown in table 3.17.

Table 3.17: Priority value of alternative locations

Priority value of location n_1: 0.1613
Priority value of location n_2: 0.2258
Priority value of location n_3: 0.1935
Priority value of location n_4: 0.2581
Priority value of location n_5: 0.1613

3.3.2 Development of integer programming to optimize capacity

As a stand-alone technique, the AHP is capable of determining the priority value for each potential locations. It is not, however, capable of determining the optimal mix of the potential facilities locations considering resource constraints or capacity constraints. Incorporating a 0-1 integer programming model provides such capability (Beaujon *et al.*, 2001, Kyparisis *et al.*, 1996, Liberatore and Titus, 1983 and Wolsey, 1998). The 0–1 integer programming model is based on the premise that the decision maker wants to define a capacity that provides optimal value while meeting specific constraints.

The general formulation for the optimization component is as follows:

i	Individual potential facility location
n	Number of alternative potential facilities location
j	Individual potential market or demand point
m	Number of alternative potential markets or demand points
D_j	Expected average annual demand from market j
A_i	Fixed cost per year associated with capacity
b_i	Cost per unit capacity at each facility i
C_i	Capacity at each facility location i
$A_i + b_i C_i$	Total cost per year for capacity C_i at location i
M_i	Maximum capacity for location i

C_{ij}	Cost of transportation per unit from facility i to market j
P_i	Priority ranking of facility location at i as calculated using AHP
B	Maximum available budget
X_{ij}	Quantity to be shipped from facility i to market j
$Y_i = 1$	if capacity allocation has to done at facility i
$Y_i = 0$	if capacity allocation has not to done at facility i
$Z_1 =$	Total priority
$Z_2 =$	Total cost

Objective functions

$$Z_1(\text{Maximize}) = \sum_{i=1}^{n}(P_i \times Y_i)$$

$$Z_2(\text{Minimize}) = \sum_{i=1}^{n}\sum_{j=1}^{m} C_{ij}X_{ij} + \sum_{i=1}^{n}(A_i + b_i C_i)\times Y_i$$

Subject to

$$(A_i + b_i C_i)\times Y_i \le B \qquad (1)$$

$$\sum_{j=1} X_{ij} \le Y_i M_i \qquad \text{for all } i \qquad (2)$$

$$\sum_{j=1}^{m} X_{ij} = C_i \qquad \text{for all } i \qquad (3)$$

$$\sum_{i=1}^{n} X_{ij} = D_j \qquad \text{for all } j \qquad (4)$$

$$Y_i \; \varepsilon \; \{0,1\} \qquad (5)$$

First objective function maximizes the total priority where as the second objective function minimizes the total cost along the supply chain. The constraint in equation 1 specifies that the total cost should not exceed the budget. The constraint in equation 2

C_{ij} Cost of transportation per unit from facility i to market j

P_i Priority ranking of facility location at i as calculated using AHP

B Maximum available budget

X_{ij} Quantity to be shipped from facility i to market j

$Y_i=1$ if capacity allocation has to done at facility i

$Y_i=0$ if capacity allocation has not to done at facility i

$Z_1=$ Total priority

$Z_2=$ Total cost

Objective functions

$$Z_1\text{(Maximize)}=\sum_{i=1}^{n}(P_i \times Y_i)$$

$$Z_2\text{(Minimize)}=\sum_{i=1}^{n}\sum_{j=1}^{m}C_{ij}X_{ij} + \sum_{i=1}^{n}(A_i + b_iC_i)\times Y_i$$

Subject to

$$\sum_{i=1}^{n}(A_i + b_iC_i)\times Y_i \leq B \qquad (1)$$

$$\sum_{j=1}^{m}X_{ij} \leq Y_iM_i \quad \text{for all } i \qquad (2)$$

$$\sum_{j=1}^{m}X_{ij} = C_i \quad \text{for all } i \qquad (3)$$

$$\sum_{i=1}^{n}X_{ij} = D_j \quad \text{for all } j \qquad (4)$$

$$Y_i \ \varepsilon \ \{0,1\} \qquad (5)$$

First objective function maximizes the total priority where as the second objective function minimizes the total cost along the supply chain. The constraint in equation 1 specifies that the total cost should not exceed the budget. The constraint in equation 2 enforces that the amount produced in the facilities location can not exceed its capacity. The constraint in equation 3 specifies that the amount shipped to customer is equal to the facilities location capacity. The constraint in equation 4 specifies that the amount shipped to customer must cover demand. The constraint in equation 5 specifies about the capacity allocation at each location i.

3.3.2.1 Results and discussion

For optimizing capacity, 0-1 integer programming is used and it is solved by using LINDO 6.1. The input parameters for integer programming given in table 3.18 and transportation cost ($) per unit from location to market given in table 3.19 are considered. Decision variables are shown in table 3.20-3.21 while considering Z_1. The result shows (see table 3.21) that the facilities has to be opened at location n_1, n_2, n_3, n_4 and n_5 with capacity 150,000, 300,000, 100,000, 400,000 and 150,000. The units of products that have to be shipped from facilities to market are shown in table 3.20. For example, the units of products that have to be shipped from location n_1 to market m_1, market m_2, market m_3, market m_4 and market m_5 are 150,000, 0, 0, 0 and 0 units respectively. Decision variables are shown in table 3.21, table 3.22 and table 3.23 while considering Z_2. The result shows (see table 3.23) that the facilities have to be opened at location n_1, n_4 and n_5 with capacity 300,000, 400,000 and 400,000. The units of products that have to be shipped from location to market are shown in table 3.22. For example, the units of products that have to be shipped from location n_4 to market m_1, market m_2, market m_3, market m_4 and market m_5 are 0, 300,000, 0, 100,000 and 0 units respectively.

Table 3.18: Input parameters

D_j (units)	150,000	300,000	300,000	200,000	150,000
M_i (units)	300,000	300,000	350,000	400,000	400,000
A_i (\$)	2000,000	2100,000	2200,000	2000,000	1900,000
b_i (\$)	1	1	1	1	1
P_i in a scale of 310	50	70	60	80	50
B (\$)	15000,000				

Table 3.19: Transportation cost (\$) per unit from location to market

	m_1	m_2	m_3	m_4	m_5
n_1	1	1	1	2	1
n_2	1	2	1	2	2
n_3	2	1	2	1	1
n_4	1	1	2	2	1
n_5	2	2	1	1	1

Table 3.20: Quantity shipped from location to market for objective (Z_1) by using LINDO 6.1

	m_1	m_2	m_3	m_4	m_5
n_1	150,000	0	0	0	0
n_2	0	0	200,000	100,000	0
n_3	0	0	0	100,000	0
n_4	0	300,000	100,000	0	0
n_5	0	0	0	0	150,000

Table 3.21: Capacity of the location for objective (Z_1) by using LINDO 6.1

	n_1	n_2	n_3	n_4	n_5
Y_i	1	1	1	1	1
C_i (units)	150,000	300,000	100,000	400,000	150,000
Total priority (Z_1)	310				

Table 3.22: Quantity shipped from location to market for objective (Z_2) by using LINDO 6.1

	m_1	m_2	m_3	m_4	m_5
n_1	150,000	0	0	0	150,000
n_2	0	0	0	0	0
n_3	0	0	0	0	0
n_4	0	300,000	0	100,000	0
n_5	0	0	0	300,000	100,000

Table 3.23: Capacity of the location for objective (Z_2) by using LINDO 6.1

	n_1	n_2	n_3	n_4	n_5
Y_i	1	0	0	1	1
C_i (units)	300,000	0	0	400,000	400,000
Total cost (Z_2)	$8100,000				

3.3.3 Development of simulated annealing algorithm for capacity

Simulated Annealing (SA) algorithm is a powerful random search algorithm based on iterative improvement originally introduced by Metropolis *et al.* (1953) and later implemented by Kirkpatrick *et al.* (1983) to solve combinatorial problems. It is a random-search technique which exploits an analogy between the way in which a metal cools and freezes into a minimum energy crystalline structure (the annealing process) and the search for a minimum in a more general system which forms the basis of an optimization technique for combinatorial and other problems. It is a method that has been successfully applied in many complex optimization problems (Sánchez-Ante *et al.*, 1999, Yang *et al.*, 2000, Abido, 2000, Robini *et al.*, 1999). There is no universally accepted definition of 'optimum' in multiple objective optimization as in single-objective optimization, which makes it difficult to even compare results of one method to another, because normally the decision about what the 'best' answer is corresponds to the so-called human decision maker (Coello Coello, 1999). So, there exists no generally accepted solution approach for multiple objective optimization problems which can satisfy the decision makers. SA has been applied to numerous problems in Operations Research/Management Science, such as cell formation (Adil *et al.*, 1997), scheduling with resource constraints (Gemmill and Tsai, 1997), machine conditioning (Khan *et al.*, 1996), scheduling with multi-level product structure (Kim and Kim, 1996), lot sizing (Kuik and Salomon, 1990 and Kuik *et al.*, 1993), and guillotine cutting (Parada, 1998). A good survey of SA applications can be found in (Koulaman, 1994). However, none of these papers discussed multi-objective optimization programming (MOOP) as considered by Sarker and Newton (2000). The detailed SA algorithm used in the present study is given below.

Step 1 Generate 100 feasible points randomly within the range. Determine Z_1 and Z_2 for all 100 points. Find the maximum Z_1 and Z_2 and minimum Z_1 and Z_2 from these 100 solutions. Find the temperature T as follows:

$$T = (\text{maximum}\, Z_1) + (\text{maximum}\, Z_2) - (\text{minimum}\, Z_1) - (\text{minimum}\, Z_2)$$

Step 2 Generate x_{ij} randomly and determine Z_1 and Z_2 and set $k = 0$

Step 3 Generate a neighborhood solution and determine Z_{1new} and Z_{2new}.

If $Z_{1new} > Z_1$ and $Z_{2new} < Z_2$ or $Z_{1new} - Z_{2new} > Z_1 - Z_2$, then accept the new solution and set $k = k+1$.

Else Determine $F = e^{(Z_1 - Z_2 - Z_{1new} + Z_{2new})/T}$. Generate a random number r between zero and one. If $F > r$, then accept the new solution otherwise go with the previous solution and set $k = k+1$.

Step 4 If $k > 200$ go to Step 5 otherwise go to step 3.

Step 5 Decrease T as $T = 0.85*T$ and repeat Step 3 if T is less than a defined temperature otherwise stop.

The flow chart of simulated annealing algorithm for multi-objective programming for the capacity is given in the figure 3.21.

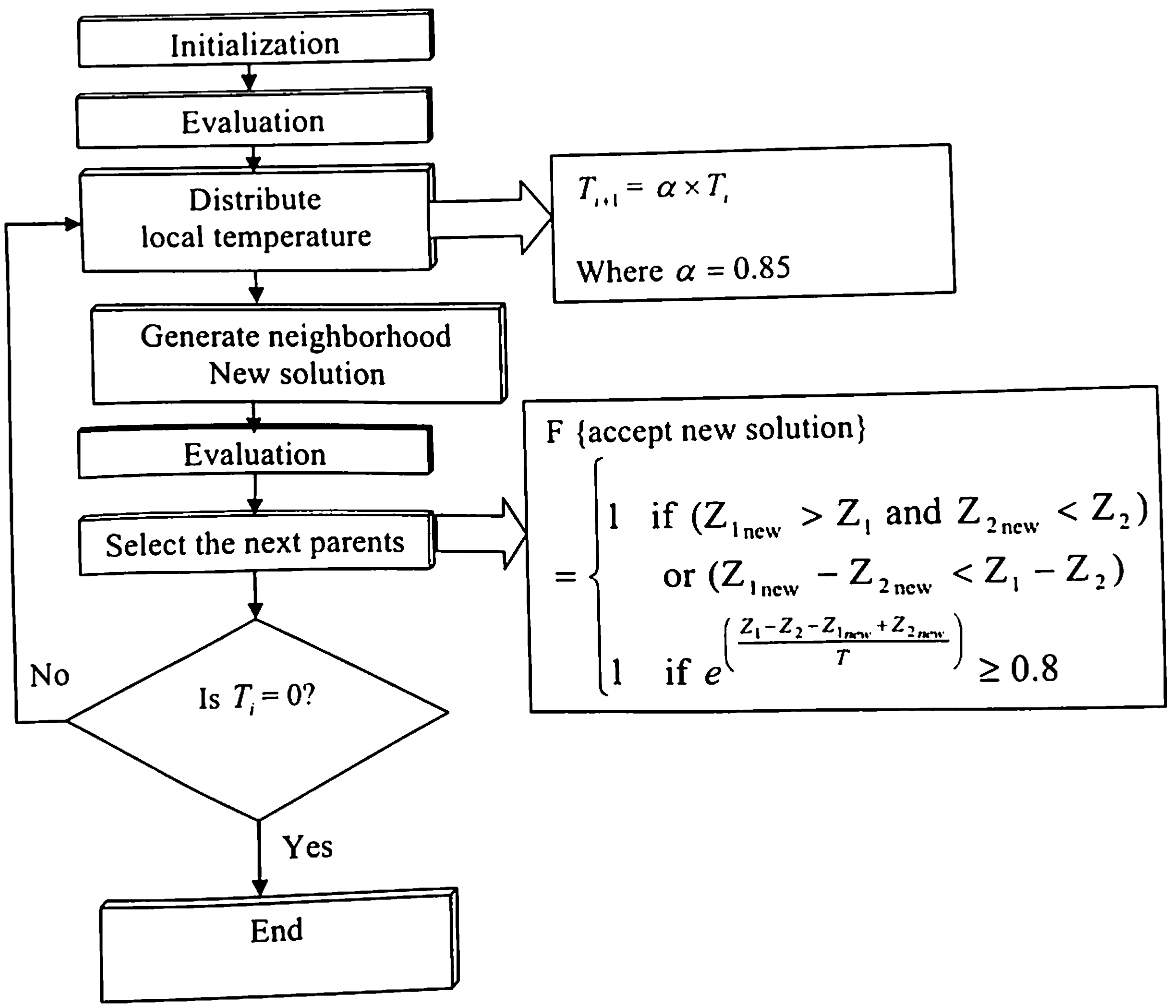

Figure 3.21: Flowchart of simulated annealing algorithm for multi-objective programming for capacity

3.3.3.1 Results and discussion

The input parameters for integer programming given in table 3.18 and transportation cost ($) per unit from location to market given in table 3.19 are considered. Highly user-friendly software, SA algorithm has been developed to solve the problem . Decision variables are shown in table 3.24 and table 3.25 while considering both Z_1

and Z_2. The result (see table 3.25) shows that the manufacturing plant has to be opened at location n_1, n_2, n_3 and n_5 with capacity 247,000, 248,000, 248, 000 and 357,000 considering both Z_1 and Z_2. The units of products that have to be shipped from plants to market are shown in table 3.24. For example, the units of products that have to be shipped from manufacturing plant n_1 to market m_1, market m_2, market m_3, market m_4 and market m_5 are 48,000, 99,000, 99,000, 1,000 and 0 units respectively.

Table 3.24: Quantity shipped from location to market for objective (Z_1) and (Z_2) by using simulated annealing algorithm

	m_1	m_2	m_3	m_4	m_5
n_1	48,000	99,000	99,000	1,000	0
n_2	49,000	99,000	99,000	1,000	0
n_3	49,000	99,000	99,000	1,000	0
n_4	0	0	0	0	0
n_5	4,000	3,000	3,000	197,000	150,000

Table 3.25: Capacity of the location for objective (Z_1) and (Z_2) by using simulated annealing algorithm

	n_1	n_2	n_3	n_4	n_5
Y_i	1	1	1	0	1
C_i (units)	247,000	248,000	248,000	0	357,000
Total cost (Z_1)	$10750,000				
Total priority (Z_2)	230				

3.4 Development of decision support system framework for selection of warehouse methodology

The fierce competition that crept deep into today's business environment has certainly forced the business world to make some radical changes in their business processes in order to improve their quality, delivery speed and service. In order to rise up to the ever-growing expectations of customers for faster delivery and greater reliability both manufacturer and service personnel are desperately looking for better ways to manage their material flows. This has shifted everyone's attention towards effective and efficient supply chain management. Therefore, to stay competitive, enlightened companies have strived to achieve greater coordination and collaboration among supply chain partners, in an approach called "competitive supply chain". It is the integration of traditional supply chain and e-supply chain, which offers the benefits of traditional supply chain and e-supply chain. One of the logistics manger's most important tasks is to decide the optimal number of locations and capacity of warehouses in the supply chain through proper trade-off of different costs. Some of the techniques used for global analysis of locations for warehouses are the following: factor qualification systems (Eilon, 1982); gravitational methods (Douglas and Moses, 1996); linear programming techniques with exact (Sweersey and Thakur, 1995) or heuristic (Hansen et. al., 1994) calculations; and cluster and cost analysis (Fuente and Lozano, 1997). The four most significant factors for deciding the number of warehouses are: cost of lost sales, inventory costs, warehousing costs and transportation costs (Lambert *et al.*, 1998). The cost of lost sales is extremely important to any company but also most difficult to calculate and predict, and varies from company to company and from industry to industry (Johnson *et al.*, 1999). The cost of inventory increases with the number of facilities because every company has safety stock at every facility. Some companies have specific warehouses dedicated to a particular product or product group. This means that both slow and fast moving items are stocked and, therefore, more space is required (Lambert *et al.*, 1998). The more the number of warehouses, the more the costs incurred. There is the cost of more space, more workers to be employed and more equipment needed. Warehousing costs decreases as the total space occupied increases, especially when the company leases or rents the space (Lambert *et al.*, 1998). Quantity discounts are often offered on public and contract warehouses if the company rents space in multiple locations (Coyle *et al.*, 1996). Transportation costs will at first decline as the number of facilities increases, but will eventually increase as the number of facilities increase as a result of inbound and outbound transportation costs. The total transportation cost of products must be measured considering both quantity and distance. This will lead to higher costs charged by the transporters due to smaller loads. The total transportation costs for the distribution of the products to the customers may also increase due to minimum charges (Mulcahy, 1994). Some factors to consider when evaluating the optimal number of warehouses include: the level of customer service required; the number of customers; their location and buying habits; and the amount and type of electronic data interchange taking place between producers and consumers (Bloomberg *et al.*, 2002). One of the important aspects of the supply chain management is to select a suitable distribution network. As a proper distribution network can provide a good competitive advantage by reducing the response time, it has become imperative on the part of organizations to develop a strategic and innovative way to design their physical distribution network. It is necessity to develop an automated and computerized tool, which can aid the supply chain manager in designing the distribution network for a given product and demand pattern taking into account all physical and practical constraints. Chopra and Meindl (2001) classified the distribution network into six types: manufacturer storage with direct shipping, manufacturer storage with direct shipping and in transit merge, distributor storage with package carrier delivery, distributor storage with last mile delivery, manufacturer/distributor storage with customer pickup and retail storage with customer pickup. The number of warehouses depends on the distribution network. Design of a distribution network is certainly the most important decision for any manufacturing sector and service sector. This is a strategic decision and hence affects the future direction of company to a great extent. From above discussion it is obvious that warehousing is an integral part of every logistics and supply chain network system and plays a vital role in providing the desired level of customer service at the lowest possible cost. It serves as an important link between the producer and the customers.

Basic functions of warehouse

The basic functions that exist in the traditional warehouse, can according to Frazelle (1996), be divided into the following:

- Receiving
- Pre-packing
- Put-away
- Storage
- Order picking
- Packing and/or pricing
- Sortation
- Packing and shipping
- Cross-docking

Receiving: The concept of receiving involves the orderly receiving of all materials by the warehouse, provided that the material is the right quantity, quality and type of material as per description on the order. Included in this is the correct disbursement of materials to the storage-pick staging area (Mulcahy, 1994).

Pre-packing: The activity of pre-packing is usually performed when the order arrives in bulk. This would then be packed singly in merchandisable quantities or in combinations with other parts to form kits or assortments. An entire receipt of merchandise may be processed at once or a portion may be held in bulk and processed later. This may be done if the packaging takes up a lot of extra cubic space or when part of it is common to several kits (Frazelle, 1996).

Put-away: Put-away refers to merchandise placed in storage. It includes the movement of material to the rightfully assigned put-away locations as well as placing it into those locations (Tompkins *et al.*, 1996).

Storage: The merchandise is physically contained in anticipation of the demand. The form of storage to be used is dependent on a number of factors such as: size and quantity of the products and the specific handling characteristics of the product or its containers (Frazelle, 1996).

Order picking: The items will be removed from storage to meet specific demands as desired by the customer. This is usually also the basic service provided by a warehouse to the customer. Most of the warehouse designs are usually based on this (Tompkins *et al.*, 1996).

Packing and/or pricing: Packing and/or pricing may according to Frazelle (1996), be done as an optional step after the picking process. For the sake of more convenient use, individual items or assortments are boxed. If these activities are performed after the picking, the advantage is more flexibility in the use of on-hand inventory. Pricing is current and up to date until the time the product is sold. Pre-pricing of the merchandise while in storage and pre-packed will lead to re-pricing due to some of the prices that may need adjustment.

Sortation: The sortation function involves the taking of heterogeneous products and sorting them into heterogeneous stocks, and bringing together similar stocks from different sources (Johnson *et al.*, 1999). From a picking perspective, it may happen that an order has more than one item on the picking slip and the consolidation of the product is made incorrectly as the picks are made.

Packing and shipping: Activities included in packaging and shipping may be: checking of orders for completeness, packaging merchandise in an appropriate shipping container, ensuring that it is protected and that the relevant shipping documents have been prepared. The shipments are weighed in order to establish the shipping charges, the orders accumulated for the outbound carriers and the trucks to be loaded (Fawcett *et al.*, 1992).

Cross-docking: Cross-docking refers to inbound material that is moved directly from receiving to the shipping dock, essentially filling orders from receiving (Frazelle, 1996). The product is therefore never stored in the warehouse and this function has led to a reduction in warehouses or distribution centres due to the fact that there is less product to be stored. Apart from the basic functions that form part of the warehousing function, there are some specialized functions that can be performed.

Specialized functions in warehousing: Ackerman (1997) is of the opinion that the following functions are merely the basic functions that every warehouse should perform in their basic day-to-day operations. Apart from warehouses that specialize in certain areas or functions, the functions of these various warehouses can be divided into:

- Stockpiling
- Product mixing
- Consolidation

- Distribution

Stockpiling: Stockpiling refers to a situation in which a warehouse is used as a reservoir to handle the production overflow. These reservoirs are needed in two situations –one is where there is seasonal production and level demand, and the other is where there is level demand and seasonal production. An example may be a canner of tomatoes. This individual will build a warehouse during harvest time although the demand is throughout the year. On the other hand, there is the toy manufacturer for whom the highest demand is usually in certain seasons or holidays. However, he needs to stockpile to accommodate seasonal demand (Hach, 1995).

Product mixing: Certain manufacturers may have product-oriented factories in different locations and they can make use of a product-mixing warehouse to combine their entire line of items. For example, one food manufacturer may have factories in several communities and every factory produces a distinct line of products. In order to satisfy the customer's demand in terms of full carloads or truckloads containing a mixture of the products, which are offered, there may be warehousing points, which can be used as an economical mixing point for the products (Hach, 1995).

Consolidation: Consolidation is the use of warehousing in order to gather all goods that need to be shipped to its final destination, i.e. the agent or distributor. Here, the advantage lies in the fact that the distributor needs to keep less stock and can have more inventory turns by stocking the right product. With consolidation, there is also savings that can be achieved through volume loads carried on the outbound shipping side (Hach, 1995).

Distribution: This is the opposite of consolidation. Whereas consolidation is based on a pull-system where all products have to come to one point/location, distribution places the product at various locations in order to get the product as close as possible to the customer. Both consolidation and distribution improve time and place utility of inventory (Ackerman, 1997).

A decision support system framework is developed for warehouse methodology in supply chain network, which consists of five phases and it is shown in figure 3.22. Each phase is discussed below.

Ownership decision (Phase I): Various warehousing options exist. These are private warehousing, public warehousing and contract or dedicated warehousing. The advantages of private warehouses are: greater control; flexibility; less costly in the long term; better use of human resources; tax benefits and intangible benefits. Where as the shortcomings are: financial constraints and low rate of return. The advantages of public warehouses are: conservation of capital; use of space to meet peak requirements; reduced risk; economies of scale and knowledge of exact warehousing costs. Where as the shortcomings are: communication problems; lack of specialized services and space may not be available. Contract warehousing is a combination of the services offered by public and private warehouses. This practice is defined as "a long term contract mutually beneficial arrangement, which provides unique and specially tailored services exclusively to one client, where vendor and client share the risks associated with the operation". This type of arrangement is very similar to many partnerships that are evolving along the supply chain (Johnson *et al.*, 1999). Therefore, ownership decision of the warehouse should be taken based on competitive strategy, constraints and objectives by analysing the advantages and shortcomings of each option.

Priority determination for feasible locations of warehouses (Phase II): The objective of second phase is determination of priority value for feasible locations of warehouses. The set of feasible locations should be larger than the desired number of facilities to be set up so that a precise selection may be made in phase III. Constant sum model is developed for determination of the priority value for feasible locations of warehouses by considering warehouse location factors.

Optimal number and capacity of warehouses (Phase III): During the third phase, the feasible locations with better priority are considered. The 0-1 integer programming is developed for determination of optimal number of warehouses and their capacity in supply chain network.

Size of warehouse (Phase IV): During the fourth phase, size of the warehouse has to be found out. Size simply refers to the overall cubic content of the building– its length, width and height. Determining the building volume is a task complicated by the many factors that affect the size decision. The capacity of the warehouse is found out in terms of number of units of product and it plays an important role to determine the size of the warehouse. But such factors as material handling system to be used, aisle requirements, stock layout arrangements, dock requirements, local building codes, office area and product throughput (both now and in the future) also influence the final choice of building size. The starting point for determining the capacity of the warehouse is the minimum space required for accommodating the inventory stored in the building over time. The remaining factors influence size by adding to the basic size.

Internal warehouse management (Phase V): During the fifth phase, internal warehouse management has to be found out. No uniform principle of layout is appropriate to all warehouse design problems. Several principles may be considered and a good layout would represent a compromise amongst the problems of maintaining an item in stock, keeping track of items so that it can found readily and correctly and minimising the total physical effort of moving items into and out of stock. The principle of warehouse layout and principles of warehouse order picking and assembly disciplines should be used for internal warehouse management.

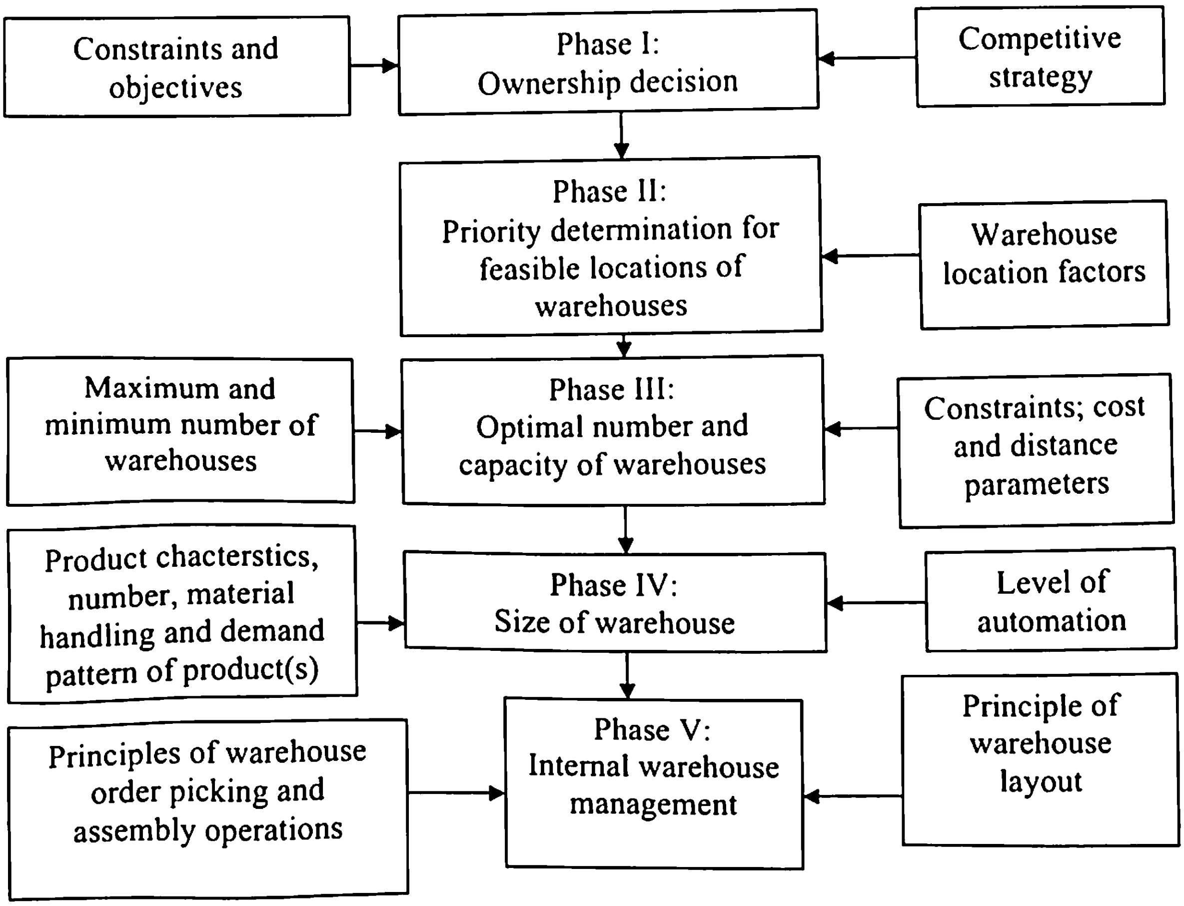

Figure 3.22: Decision support system framework for warehouse methodology

Company X is involved in an automotive production. Most of the products are world class and competitive supply chain network is a key competitive factor in the business. The logistics executives now face the problem to develop the competitive supply chain. Based on preliminary analysis, the logistics executives identified 14 possible locations for warehouses. The key phases of framework for warehouse methodology in supply chain network are the second and third. The second and third phases are discussed below.

3.4.1 Development of constant sum model for determination of the priority value for feasible locations

Engineering and research managers are frequently faced with multilevel decisions under conflicting objectives and criteria. The strategies need to be developed to fulfil multiple goals; allocate resources to implement multiple strategies; and to evaluate the projects and programs in terms of time, cost, and performance characteristics. A thorough analysis of the problem is required along with identification of the important attributes involved. The selection of attributes has been determined through literature survey and discussions held with experts. The attributes used in multi-attribute decision model i.e. constant sum model for determination of the priority value for feasible locations of warehouses are as follows:

- Workforce [WRF]
- Social and culture [SOC]
- Infrastructure [INF]
- Suppliers [SUP]
- Markets and customers [MAC]
- Economy [ECO]
- Government and policies [GAP]
- Legal and regulatory [LAR]
- Costs [CST]
- Characteristics of location specific [LSC]

In the constant sum model, n (n-1)/2 pairs are formed for ranking 'n' alternatives under consideration. Then the decision makers/experts are asked to distribute a total of 100 points between the elements/alternatives with respect to each other for each attribute. For example, if one alternative is viewed to be four times as high as the other one, the decision maker/expert allocates 80 and 20 points, respectively. If one is considered slightly higher than the other, the allocation may be 52 to 48. If they are equal in value, each is given 50 points. After, all the comparisons are made, the subjective values implicit in the decision maker's judgement are recovered using step 5 to 9 of the constant-sum algorithm.

3.4.1.1 Algorithm

The algorithm for constant sum method is given below (Kocaoglu, 1983).

Step 1. Define the problem and determine the objectives.

Step 2. Identify the alternatives available.

Step 3. Determine the attributes/criteria/performance indicators that govern the problem.

Step 4. Form the n (n-1)/2 random pairs of alternatives, where n is the number of alternatives.

Step 5. Obtain constant sum measurements from the decision maker/expert for these n (n-1)/2 random pairs and form the matrix 'A' by comparing column elements with row elements. Obtain matrix 'B' by taking the ratio of comparisons for each pair from matrix 'A'.

Step 6. Obtain a new matrix 'C' by dividing each element in a column of the matrix 'B' by the element in the next column.

Step 7. Obtain the mean and standard deviation (SD) of each column.

Step 8. If the SD is non-zero then go to step 9 else go to step 10.

Step 9. In that case, Matrix 'C' is repeated for all n! orientations of the n elements/alternatives. The normalised relative values of the elements/ alternatives are obtained for each orientation. The mean of the relative values is calculated as the final value for each element/alternative, and the variance in the distribution of the relative values is used as a measure of internal inconsistency. The inconsistency measure is computed as follows:

$$Inconsistency = \sqrt{(1/n)\sum_{i=1}^{n}(1/n!)\sum_{j=1}^{n!}(r_{sub_i} - r_{ij})^2}$$

where r_{ij} is the relative value of element i in jth orientation and r_{sub_i} is the average subjective relative value of element *i*.

$$r_{sub_i} = (1/n!)\sum_{j=1}^{n!} r_{ij}$$

If inconsistency is greater than 0.04, then go to step 4 and change the total points and repeat until SD is 0 or inconsistency is less than 0.04.

Step 10. Assign a value of 1.0 to the last element/alternative and calculate the relative value of other alternatives/elements by the ratios indicated as the mean of each column.

Step 11. Normalize the relative values (priority values).

Step 12. The alternative analysis for the remaining attributes to be carried out in the similar manner as above.

Step 13. The desirability index for each alternative is calculated by summing the priority values.

Highly user-friendly software, the multi-attribute decision model i.e. constant sum model is developed in VC++ to aid the user for pair-wise comparison of the attributes as well as for the alternatives and for analysing the user inputs. The attributes are compared with each other in a pair-wise comparison with respect to the case situation discussed in table 3.2. The priority values for feasible locations of warehouses and desirability index for feasible locations of warehouses are shown in table 3.26 and table 3.27. Eight locations having high desirability index are considered out of 14 feasible locations for warehouses.

Table 3.26: Priority values for feasible locations of warehouses

	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_9	W_{10}	W_{11}	W_{12}	W_{13}	W_{14}
[WRF]	0.12	0.08	0.12	0.12	0.08	0.1	0.08	0.03	0.04	0.05	0.03	0.04	0.06	0.05	0.08
[SOC]	0.05	0.14	0.12	0.07	0.1	0.12	0.125	0.07	0.0275	0.01	0.03	0.02	0.0675	0.05	0.14
[INF]	0.12	0.05	0.1225	0.11	0.11	0.05	0.12	0.01	0.04	0.13	0.0675	0.01	0.04	0.02	0.05
[SUP]	0.08	0.03	0.07	0.08	0.1	0.1	0.13	0.1	0.05	0.04	0.06	0.04	0.08	0.04	0.03
[MAC]	0.15	0.11	0.13	0.1	0.1	0.16	0.04	0.02	0.04	0.05	0.06	0.02	0.01	0.01	0.11
[ECO]	0.1	0.16	0.04	0.02	0.15	0.11	0.13	0.1	0.01	0.04	0.03	0.04	0.02	0.05	0.16
[GAP]	0.05	0.12	0.11	0.1	0.11	0.11	0.12	0.02	0.06	0.02	0.04	0.05	0.06	0.03	0.12
[LAR]	0.12	0.05	0.12	0.11	0.08	0.08	0.07	0.08	0.04	0.1	0.03	0.01	0.04	0.07	0.05
[CST]	0.15	0.11	0.13	0.1	0.08	0.03	0.07	0.08	0.11	0.03	0.03	0.02	0.04	0.02	0.11
[LSC]	0.12	0.11	0.11	0.05	0.12	0.11	0.1	0.1	0.03	0.04	0.03	0.03	0.01	0.04	0.11

Table 3.27: Desirability index for feasible locations of warehouses

W_1	1.47
W_2	1.295
W_3	1.4525
W_4	1.3
W_5	1.46
W_6	1.32
W_7	1.4
W_8	0.92
W_9	0.6975
W_{10}	0.68
W_{11}	0.5475
W_{12}	0.4
W_{13}	0.5175
W_{14}	0.54

3.4.2 Development of integer programming for optimal number and capacity of warehouses

A linear programming model has been formulated to minimize the transportation cost, fixed and operating cost of the warehouse and inventory cost along the supply chain to determine optimal number and capacity of warehouses. Linear programming is a mathematical programming technique to optimize performance under a set of resource constraints as specified by an organization. The word linear is used to describe the relationship between the decision variables, which are directly proportional (Jacob, 2002; Chandan *et al.*, 1996; Murty, 1976; Zeleny, 1974; Garvin, 1980; Strayer, 1979 and Frazer, 1968). The word programming means planning activities in a manner that achieves some optimal result with available resources. A program is optimal if it maximizes or minimizes some measure or criterion of effectiveness, such as profit, contribution, sales, cost etc. (James *et al.*, 1994). Thus linear programming indicates the planning of decision variables, which are directly proportional; to achieve the optimal result considering the limitation within which the problem is to be solved (Ravindran *et al.*, 2000). A Linear programming problem is characterized by the following elements:

- An objective function that is a linear function of the decision variables. The objective function is to be maximized or minimized.
- A set of constraints, each of which must be a linear equality or linear inequality in the decision variables.
- A sign restriction that specifies for each decision variable either must be nonnegative (greater or equal to zero), or is unrestricted in sign (Murtagh, 1981; Gass, 1964; Charnes *et al.*, 1961; Vajda, 1974; Paul, 1964 and Rardin, 1998).

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The assumptions of the model are:

- Cycle inventory at any warehouse is equal to half of the demand size/month.
- Warehouses can be set up only at feasible sites.
- Total demand of all the customer pickup points is completely satisfied.
- A periodic review policy with review period of one month is used at all warehouses.
- The amortized fixed cost/ month of the warehouse is \$ $A + x$ where x is its capacity in units of product.
- The monthly operating cost of a warehouse is \$ 0.2 x_{il} where x_{il} is the quantity to be shipped from manufacturing plant i to warehouse l
- Designed capacity of the warehouse is 1.5 x_{il} where x_{il} is the quantity to be shipped from manufacturing plant i to warehouse l

The following notations are used to the model.

M_i: Manufacturing plant i where $i = 1, 2,$ -------n

W_l: Warehouse l where $l = 1, 2, 3, 4$----------m

P_c: Customer pick-up point c where c=1, 2, 3----------j

f : Maximum number of feasible warehouses that can be in the supply chain

g : Minimum number of feasible warehouses that can be in the supply chain

S_i: Maximum capacity of manufacturing plant i

S_l: Maximum capacity of warehouse l

D_{il}: Distance between manufacturing plant i to warehouse l

X_{il}: Quantity to be shipped from manufacturing plant i to warehouse l

D_{lc} : Distance between warehouse l to pickup point c

W_{lc} : Quantity to be shipped from warehouse l to pickup point c

C_1 : Transportation cost/unit/distance from manufacturing plant to warehouse

C_2 : Transportation cost/unit/distance from warehouse to customer pickup point c

D_c : Customer demand at customer pickup point c per month

A_l : fixed cost of warehouse l per month

O_l : Operating cost at warehouse l

C_h : Holding cost at the warehouse $/unit/month

C_s : Stock-out cost at the warehouse $/unit/month

$Y_l = 1$ if warehouse l is open, otherwise 0

The above objective can be mathematically represented as follows:

The objective function is to minimize the total cost. So objective function can be defined as:

Objective function= In-bound transportation cost (manufacturer to warehouse) + outbound transportation cost (warehouse to customer pick up point) + total fixed cost of the warehouses+ total operating cost of the warehouses + inventory holding cost at the warehouses + cost of lost sale)

$Z_1 = \sum_{i=1}^{i=n}\sum_{l=1}^{l=m} C_1 \times D_{il} \times X_{il}$ = In-bound transportation cost (manufacturer to warehouse)

$Z_2 = \sum_{l=1}^{l=m}\sum_{c=1}^{c=j} C_2 \times D_{lc} \times W_{lc}$ = Outbound transportation cost (warehouse to customer pick up point)

$Z_3 = \sum_{l=1}^{l=m}\left[A_l \times Y_l + 1.5 \times \sum_{i=1}^{i=n} X_{il} \right]$ = Total fixed cost of the warehouses/month

$$Z_4 = \sum_{i=1}^{i=n} \sum_{l=1}^{l=m} 0.2 \times X_{il} + \sum_{l=1}^{l=m} O_l \times Y_l = \text{Total operating cost of the warehouses/month}$$

$$Z_5 = \sum_{l=1}^{l=m} \sum_{i=1}^{i=n} 0.5 \times C_h \times X_{il} = \text{inventory holding cost at the warehouses}$$

$$Z_6 = \sum_{l=1}^{l=m} \sum_{i=1}^{i=n} 0.05 \times C_s \times X_{il} = \text{Cost of lost sales}$$

Objective function

$$Z = \sum_{i=1}^{i=n} \sum_{l=1}^{l=m} C_1 \times D_{il} \times X_{il} + \sum_{l=1}^{l=m} \sum_{c=1}^{c=j} C_2 \times D_{lc} \times W_{lc} + \sum_{l=1}^{l=m} \left[A_l \times Y_l + 1.5 \sum_{i=1}^{i=n} X_{il} \right] +$$

$$\sum_{i=1}^{i=n} \sum_{l=1}^{l=m} 0.2 \times X_{il} + \sum_{l=1}^{l=m} O_l \times Y_l + \sum_{l=1}^{l=m} \sum_{i=1}^{i=n} 0.5 C_h \times X_{il} + \sum_{l=1}^{l=m} \sum_{i=1}^{i=n} 0.05 \times C_s \times X_{il}$$

Subject to constraints

$$\sum_{l=1}^{l=m} X_{il} \le S_i \quad \forall\ i \qquad (6)$$

$$\sum_{i=1}^{i=n} X_{il} - \sum_{c=1}^{c=j} X_{lc} \ge 0 \quad \forall\ l \qquad (7)$$

$$\sum_{c=1}^{c=j} W_{lc} \le Y_l\ S_l \quad \forall\ l \qquad (8)$$

$$\sum_{l=1}^{l=m} W_{lc} = D_c \quad \forall\ c \qquad (9)$$

$$\sum_{l=1}^{l=m} Y_l \le f \qquad (10)$$

$$\sum_{l=1}^{l=m} Y_l \ge g \qquad (11)$$

$$Y_l\ \varepsilon\ \{0,1\} \qquad (12)$$

The constraint in equation 6 enforces that the amount shipped from the plant can not exceed its capacity. The constraint in equation 7 enforces that the amount shipped from the warehouse should not exceed amount shipped to the warehouse. The constraint in equation 8 enforces that the amount shipped from the warehouse can not exceed its capacity. The constraint in equation 9 specifies that the amount shipped to customer pick up point must cover its demand. The constraint in equation 10 specifies that the number of warehouses should be less than the maximum number of warehouses. The constraint in equation 11 specifies that the number of warehouses should not less than its minimum number of warehouses. The constraint in equation 12 enforces that warehouse is either open or close at each location l.

3.4.2.1 Results and discussion

LINDO 6.1 has been applied to solve the problem . To illustrate the above model, the input parameters for plants and warehouses and input parameters for warehouses and customer pick up points are given in table 3.28 and table 3.29. The number of warehouses, their capacity and total cost are calculated and it is shown in the table 3.30, table 3.31 and table 3.32 for two, three and four plants. For example, for two plants, the total cost $ 611555 is optimum for seven warehouses in the supply chain and the warehouses has to open in Y_1, Y_2, Y_3, Y_5, Y_6, Y_7 and Y_8 with capacity 3000; 8500; 6000; 7500; 9000, 6000 and 9000 units respectively. For three plants, the total cost $580010 is optimum for seven warehouses in the supply chain and the warehouses has to open in Y_1, Y_3, Y_4, Y_5, Y_6, Y_7 and Y_8 with capacity 3000; 8500; 5000; 8500; 9000; 6000 and 9000 units respectively. For four plants, the total cost $554510 is optimum for seven warehouses in the supply chain and the warehouses has to open in $Y_1, Y_3, Y_4, Y_5, Y_6, Y_7$ and Y_8 with capacity 3000; 8500; 5000; 8500; 9000, 6000 and 9000 units respectively. It is found that in all cases, the optimum number of warehouses is seven, but when number of plants is increasing, the total cost is decreasing. The relationship between number of warehouses and total cost is shown in figure 3.23, 3.24 and 3.25 for two, three and four plants.

Table 3.28: Input parameters for plants and warehouses

	M_1	M_2	M_3	M_4	A_l	O_l	S_l
W_1	600 km	550 km	375 km	2000 km	$14,000	$1,700	16,000 units
W_2	300 km	775 km	285 km	400 km	$13,000	$1,600	8,500 units
W_3	300 km	630 km	55 km	200 km	$9,000	$1,000	8,500 units
W_4	400 km	460 km	495km	1000 km	$9,000	$1,500	10,000 units
W_5	450 km	500 km	380 km	500 km	$15,000	$1,700	14,500 units
W_6	350 km	40 km	490 km	40 km	$9,000	$1,200	15,000 units
W_7	250 km	125 km	265 km	100 km	$13,200	$2,000	19,000 units
W_8	450 km	300 km	455 km	3000 km	$12,000	$2,300	25,000 units
S_l	32,000 units	21,000 units	20,000 units	20, 000 units			

Table 3.29: Input parameters for warehouses and customer pick up points

	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	D_c
P1	2,000 km	4,800 km	50 km	9.0 km	8.0 km	1,000 km	1,200 km	1,500 km	6,000
P2	200 km	1,500 km	100 km	250 km	2,400 km	1,500 km	1,000 km	2,500 km	7,000
P3	5,000 km	120 km	5,000 km	3,000 km	1,500 km	1,200 km	5,000 km	130 km	5,000
P4	50km	5,000 km	950 km	1,700 km	1,100 km	1,000 km	9,500 km	1,700 km	3,000
P5	2,500 km	1,100 km	2,600 km	1,800 km	2,500 km	10,000 km	2,600 km	300 km	4,000
P6	7,500 km	200 km	1,800 km	2,000 km	750 km	2,000 km	1,800 km	4,000 km	6,000
P7	9,500 km	200 km	3,000 km	1,000 km	9.5 km	5,000 km	3,000 km	2,000 km	7,500
P8	2,000 km	2,400 km	240 km	2,300 km	400 km	5,00 km	10,000 km	2,500 km	10,500
C_1 = \$0.01/unit/unit distance, C_2 =\$0.02/unit/unit distance C_h = \$2/unit/month C_s =\$30/unit									

Table 3.30: Total cost and capacity of warehouses for two plants (i.e. M_1, M_2)

No of warehouse	Total cost ($)	Y_1 (units)	Y_2 (units)	Y_3 (units)	Y_4 (units)	Y_5 (units)	Y_6 (units)	Y_7 (units)	Y_8 (units)
3	1147100	0	0	0	0	0	15,500	17,500	16,500
4	845135	0	0	0	0	8,500	14,500	19,500	9,000
5	666660	0	8,500	8,500	0	8,500	14,500	0	9,000
6	623785	6,500	0	8,500	0	8,500	10,500	6,000	9,000
7	611555	3,000	8,500	6,000	0	7,500	9,000	6,000	9,000
8	625155	3,000	5,000	8,500	6,000	7,500	9,000	6,000	4,000

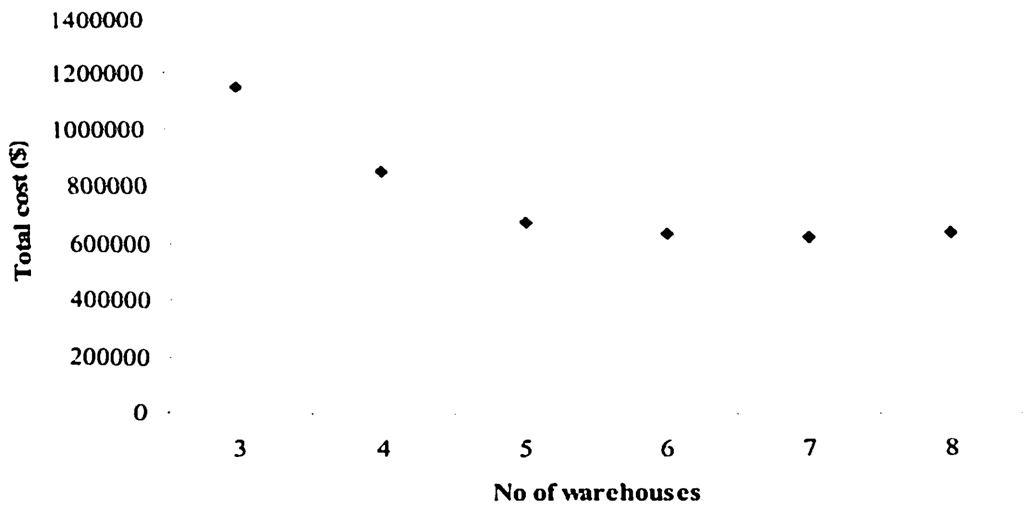

Figure 3.23: Number of warehouses and total cost for two plants (i.e. M_1, M_2)

Table 3.31: Total cost and capacity of warehouses for three plants (i.e. M_1, M_2, M_3)

No of warehouse	Total cost ($)	Y_1 (units)	Y_2 (units)	Y_3 (units)	Y_4 (units)	Y_5 (units)	Y_6 (units)	Y_7 (units)	Y_8 (units)
3	1147100	0	0	0	0	0	15,000	17,500	16,500
4	839185	0	0	0	0	8,500	14,500	16,500	9,500
5	638610	0	8,500	8,500	0	8,500	14,500	0	9,000
6	585135	6,500	0	8,500	0	8,500	10,500	0	9,000
7	580010	3,000	0	8,500	5000	8,500	9,000	6,000	9,000
8	592860	3,000	5,000	8,500	5,000	8,500	9,000	6,000	4,000

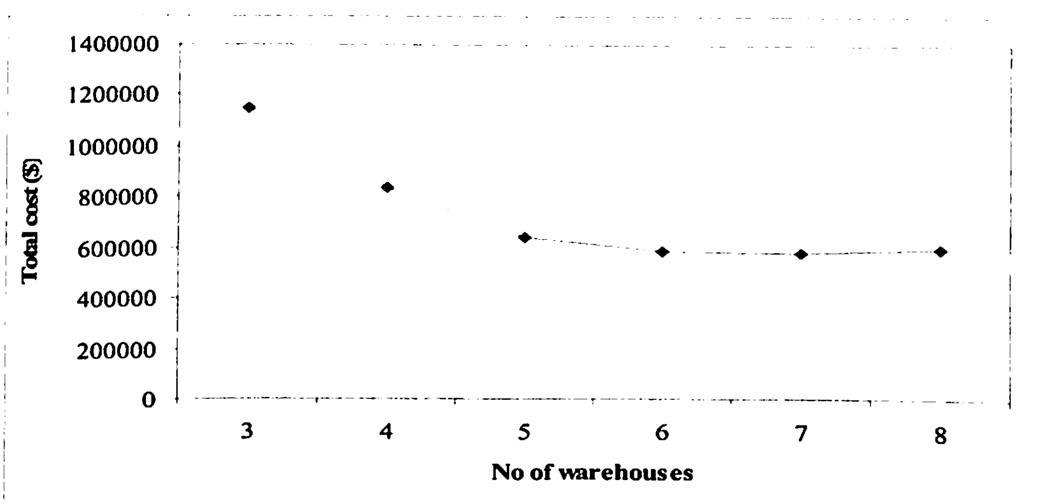

Figure 3.24: Number of warehouses and total cost for three plants (i.e. M_1, M_2, M_3)

Table 3.32: Total cost and capacity of warehouses for four plants (i.e. M_1, M_2, M_3, M_4)

No of warehouse	Total cost ($)	Y_1 (units)	Y_2 (units)	Y_3 (units)	Y_4 (units)	Y_5 (units)	Y_6 (units)	Y_7 (units)	Y_8 (units)
3	1090100	0	0	0	0	0	15,000	17,500	16,500
4	793185	0	0	0	0	8,500	15,000	16,500	9,000
5	615210	0	8,500	8,500	0	8,500	145,000	0	9,000
6	557835	6,500	0	8,500	0	8,500	10,500	0	9,000
7	554510	3,000	0	8,500	5000	8,500	9,000	6,000	9,000
8	567360	3,000	5,000	8,500	5,000	8,500	9,000	6,000	4,000

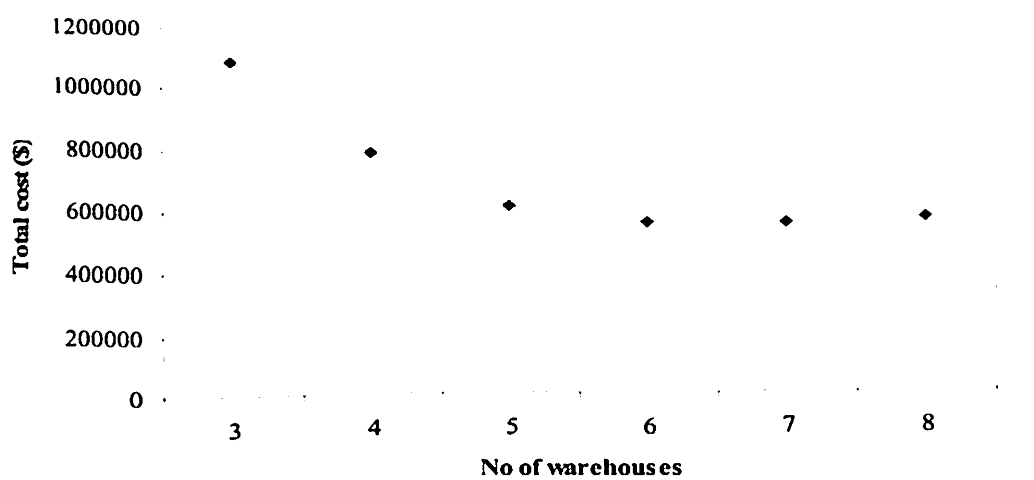

Figure 3.25: Number of warehouses and total cost for four plants (i.e. M_1, M_2, M_3, M_4)

3.4.3 Size of the warehouse

Size is probably the most important factor in designing a storage facility. Once warehouse size is determined, it acts as constraint on warehouse operations that may last 20 years or longer. Whereas internal facility layout may be changed with relative ease, altering overall size is much less likely to occur. Although the facility may be expanded later or unused space may be leased to other users, the resulting quantity of space may not be ideal. In general, the result of poor size planning is either to cause higher than necessary materials handling costs (in the case of constructing more space than needed). Specifically, what is size? Size simply refers to the overall cubic content of the building– its length, width and height. Determining the building volume is a task complicated by the many factors that affect the size decision. Although the capacity of the warehouse in terms of number units product is found out this plays an important role to determine the size of the warehouse. But such factors as material handling system to be used, aisle requirements, stock layout arrangements, dock requirements, dock requirements, local building codes, office area and product throughput (both now and in the future) also influence the final choice of building size. A starting point is the minimum space required for accommodating the inventory stored in the building over time. The remaining factors influence size by adding to the basic inventory-determined size. It can be looked into under two different conditions. The first is when there will be no significant changes in the need for space in the reasonable future. No trend in space needs is expected. However, in the short term there will be seasonal changes in space needs as sales through the warehouse and warehouse stock replenishment vary throughout the year. The second is when average inventory levels are anticipated to change over a period of years. This dynamic sizing problem seeks the best size for the warehouse in each year of the planning horizon.

Ceiling height: Determining the height for a warehouse depends on construction costs, material handling costs and product load-stacking characteristics. If we were to double the ceiling height, thereby doubling the cubic content, the construction cost would not necessarily double. The roof and floor remain the same in both cases. Balancing construction costs, however are the added materials handling costs due to the greater service time required for stacking and picking loads at a greater average height. Finally, the stacking characteristics of the stored goods can influence the desired ceiling height. Finally, the stacking characteristics of the stored goods can influence the desired ceiling height. Stability of the goods stacked individually in columns or in pallet-load units may put an upper limit on height. Height limitation may then shift from the product characteristics to the characteristics of storage and material handling equipment. Local building codes regrading sprinkler clearance may also influence the final ceiling height. Therefore, choosing a ceiling height is a matter of trading off construction and equipment costs with materials handling costs in light of product, equipment and legal constraints. In addition, there should be a minimum of extra space between the goods and effective warehouse ceiling. The additional height is determined from an analysis of uncertain future requirements. There is no particular ceiling height limitation to storage warehouses or to those with automatic storage and retrieval systems. High throughput facilities such as cross-docks or order-picking areas of distribution warehouses may limit stacking to one or two tiers with enough additional height to accommodate fire protection system.

Length versus width: The length and width or configuration, of the warehouse building should be decide in relation to the materials handling costs of moving products through warehouse and to the warehouse construction costs. Francis (1967) explored the question of configuration with the inbound-outbound dock located at X (corner) and then at Y (at the middle). The warehouse uses rectangular aisles, stores n different item types and has a floor area of S. The optimum width W^* and length L^* are found by balancing materials handling costs against warehouse perimeter costs. Perimeter costs are defined as the annual construction and maintenance costs per foot of warehouse perimeter. For the dock located at X, Francis concluded, assuming out-and-back selection in a medium throughput facility that the optimum width W^* is

$$W^* = \sqrt{\frac{C+8\times k}{2\times C+8\times k}} \times \sqrt{S}$$

and the optimum length L^{*} is

$$L^{*} = S/W^{*}$$

Where

C = The of the total cost per foot to move an item of a given type in and out of storage multiplied by the expected number of items of a given type in and out of storage per year (dollar/ft).

k = Annual perimeter cost per foot (dollar/ft)

S = Required floor area of the warehouse (sq. ft)

For the dock centred in the warehouse at location Y, the optimal width is

$$W^{*} = \sqrt{S}$$

And the optimal length is $L^{*} = \sqrt{S}$

That is, the warehouse becomes square rather than rectangular. Of these two limiting cases, locating the dock in the centre of the warehouse is the least expensive. Locating the dock at X has a total relevant cost TC_x of

$$TC_x = 2\times\sqrt{[(0.5\times C + 2\times k)\times(0.25\times C + 2\times K)]}\,\sqrt{S}$$

The relevant cost TC_y for locating the dock at Y is

$$TC_y = (0.5\times C + 4\times K)\,\sqrt{S}$$

The difference TC_x - TC_y is the premium that must be paid for locating the dock at X instead of at Y.

Space layout: Once certain decisions have been made concerning the general configuration of the warehouse, the next decision is to lay out the storage bays, shelves and aisles. The problem is one of determining the number of slots to place to place along a shelf, the number of shelves to use and whether the shelves should be placed parallel or perpendicular to the longest wall. Several formulas and decision rules have been developed to help make this decision (Bassan, 1980). Two possible shelving layouts are shown in figure 3.26 and 3.27. The product is received through a door on one side of the building and is shipped out a door on the opposite side. An item requires four movements between a door and a storage location. Dock doors are located in the centre of the building and all parts of the warehouse have an equal likelihood of being utilized. Shelving is double-sided except for shelves against a wall, which are single sided. The layout objective is to minimize the sum of materials handling cost, annual warehouse area cost and annual warehouse area cost associated with the size (perimeter) of the building. Using this concept and other constraints like warehouse capacity, one can find out optimal number of storage bays, shelves and aisles with dimension. The following notation is useful:

W = Width of double shelf (ft.)

L = Length of storage space; for example, width of a pallot (ft.)

m = Number of storage space along a shelf

h = Number of storage levels in the vertical direction

n = Number of double shelves: two single ones are considered as one double shelf

K = Total warehouse capacity in storage space

a = Width of an aisle (ft.): all aisles are assumed to be of same width

u = Length of the warehouse (ft.)

v = Width of the warehouse (ft.)

d = yearly throughout (demand) of the warehouse, in storage units. It is assumed that a storage item occupies one space unit (items/yr.)

C_h = materials handling cost of moving a storage item one length unit (dollars/ft.)

C_s = annual cost per unit of warehouse area (heat, light, maintenance) (dollar/sq. ft.)

C_p = annual cost per unit length of external walls (dollar/sq. ft.)

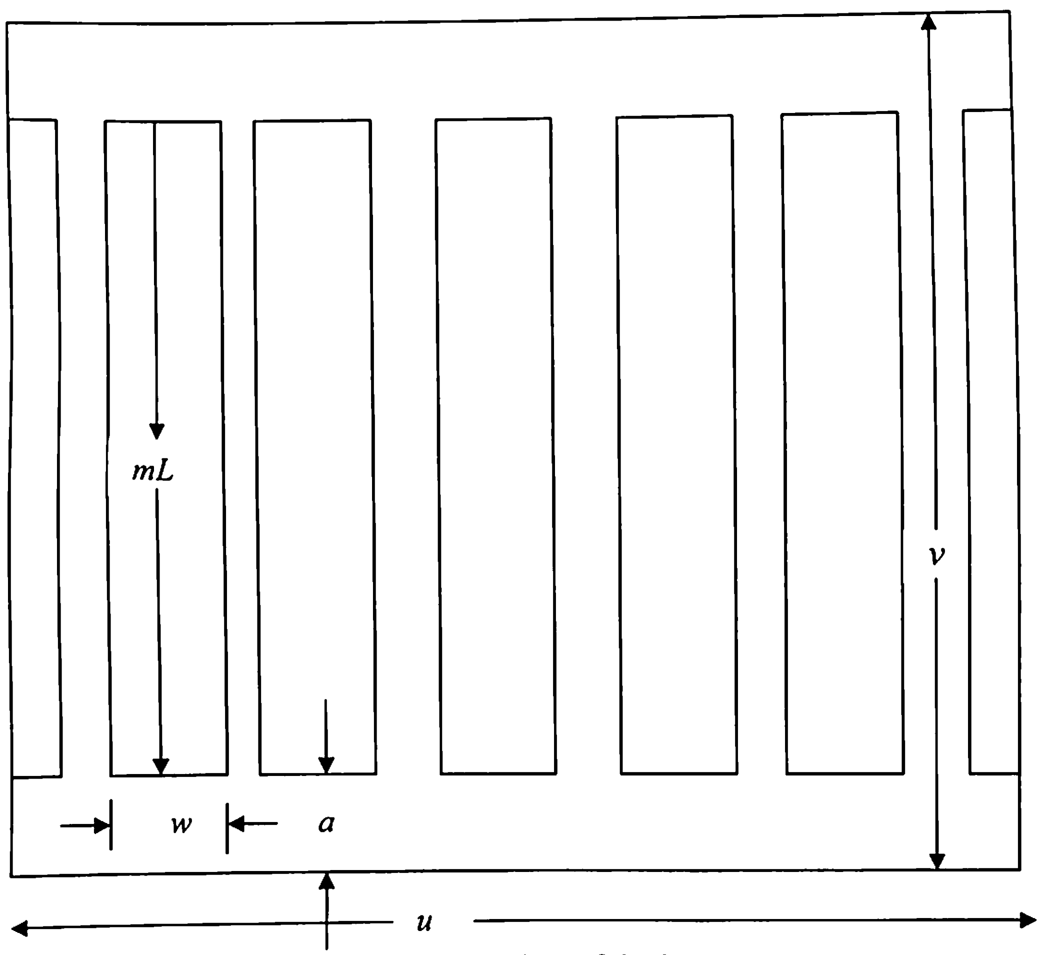

Figure 3.26: Aerial view of the layout 1

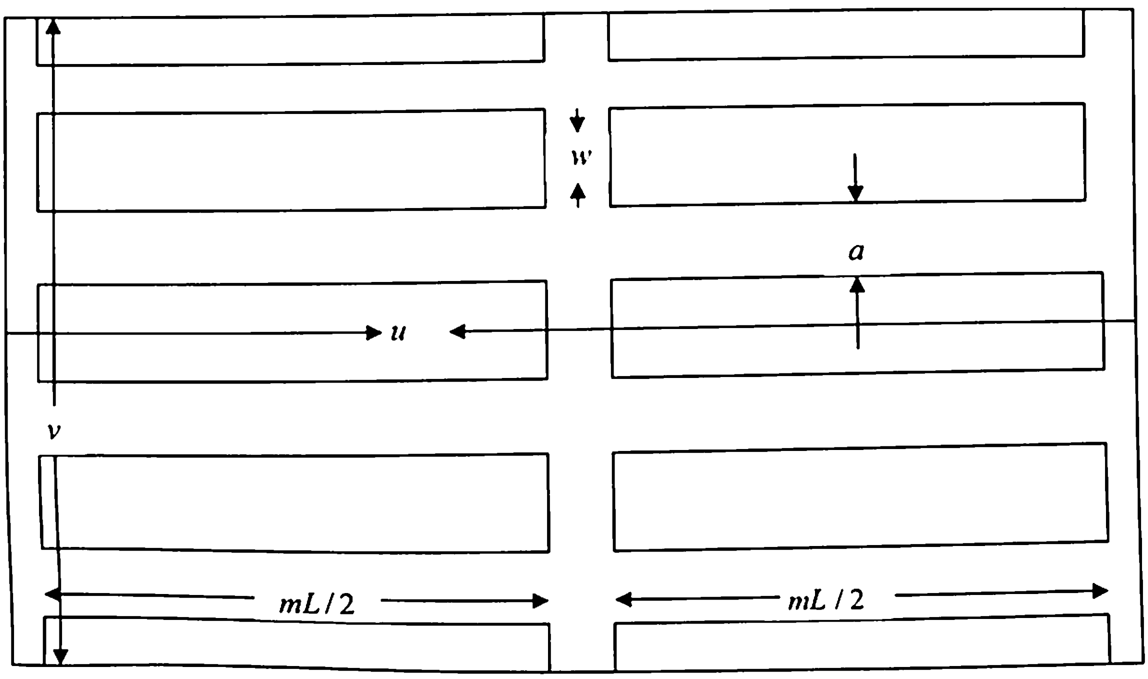

Figure 3.27: Aerial view of the layout 2

For layout 1 as shown in the figure, the optimal number of shelf spaces should be

$$m^{\bullet}_1 = \frac{1}{L}\sqrt{\left[\left(\frac{d\times C_h + 2a\times C_s + 2\times C_p}{2\times d\times C_h + 2\times C_p}\right)\left(\frac{K\times w\times L + K\times a\times L}{2\times h}\right)\right]}$$

and the optimal number double shelves is

$$n_1^{\bullet} = \frac{1}{w+a}\sqrt{\left[\left(\frac{2\times d\times C_h + 2\times C_p}{d\times C_h + 2\times a\times C_s + 2\times C_p}\right)\left(\frac{K\times w\times L + K\times a\times L}{2\times h}\right)\right]}$$

The best warehouse configuration will have a length of $u_1 = n_1^{\bullet} \times (w+a)$

and a width of $v_1 = 2\times a + m^{\bullet}_1 \times L$

For alternative layout 2 shown in the figure, the optimal parameters are

$$m_2^{\bullet} = \frac{1}{L}\times\sqrt{\left[\left(\frac{2\times d\times C_h + 3\times a\times C_s + 2\times C_p}{d\times C_h + 2\times C_p}\right)\left(\frac{K\times w\times L + K\times a\times L}{2\times h}\right)\right]}$$

and

$$n_2^{\bullet} = \frac{1}{w+a}\sqrt{\left[\left(\frac{d\times C_h + 2\times C_p}{2\times d\times C_h + 3\times a\times C_s + 2\times C_p}\right)\left(\frac{K\times w\times L + K\times a\times L}{2\times h}\right)\right]}$$

Where $u_2 = 3 \times a + \dot{m}_2 \times L$

and $v_2 = \dot{n}_2 \times (w + a)$

To minimise costs between these two layout choices, the following decision rule can be applied: If $d < \frac{C_p}{C_h}$, then layout 1 is preferred to layout 2. Layout 2 is preferred If $d > 2 \times \frac{C_p}{C_h}$. However, no conclusion can be drawn if $\frac{C_p}{C_h} < d < 2 \times \frac{C_p}{C_h}$.

3.4.4 Internal warehouse management

A warehouse has to perform a number of processing functions called as internal functions. These include receiving goods, categorisation and information update of the received goods, sorting of goods, despatching of goods to appropriate area, holding of goods, recalling, selecting and picking goods and lastly despatching goods. A warehouse design is based on the search for an adequate comprise between these function at an economic or acceptable cost. These functions are overlapping and therefore conflicts between these functions can arise. No uniform principle of layout is appropriate to all warehouse design questions. Several principles may be considered and a good layout would represent a compromise amongst the problems of maintaining an item in stock, keeping track of items so that it can found readily and correctly and minimising the total physical effort of moving items into and out of stock. The commonly accepted principles are:

- Principle of warehouse layout
- Principles of warehouse order picking and assembly disciplines

Principle of warehouse layout: The most commonly accepted warehouse design and layout principles are as follows:

- Use a one–story facility wherever possible, since it usually provides more usable space per investment dollar and usually is less expensive to construct.
- Use straight line or direct flow of goods of goods into and out of the warehouse to avoid back tracking and inefficiency.
- Use efficient materials-handling equipment and operations to improve efficiency in operations.
- Utilise existing space as completely and effectively as possible while providing both adequate accessibility and protection for the goods.
- Minimize aisle space within the constraints that the size, type and turning radius of materials handling equipment impose.
- Make maximum use of building height to utilize the building's cubic capacity effectively within the various constraints.
- Keep the items together on the basis of functional relationship, physical similarity or consumption rate.

Principles of warehouse order picking and assembly disciplines: Some basic disciplines are used to select the items needed to make up a shipment and despatch them for shipping. These include:

The area system: The merchandise is stored in the warehouse in some logical pattern. The order picker circulates through the warehouse picking each item in turn until the order is complete, then the order is transported to a packing and despatch area for shipment.

The modified area system: The system operates similar to the area system expect that inventory is divided between working stock and reverse stock. A secondary workforce is employed to replenish working stock from reverse stock.

The zone system: Each picker or group of pickers works within a specified warehouse or merchandise zone. The order is exploded that is divided down by zone and each person is sent to appropriate zone for selection and transport to a marshalling area where the order is assembled for shipment. Each zone individually operates according to the area where the order is assembled for shipment. Each zone is individually operates according to the area or modified area system. Each order is handled individually and must clear the system before next order is introduced.

The sequential system: As in the earlier discipline the order is broken by zones and each portion of order picked in the appropriate zone. After the order has been picked in one zone, it is transported to the next zone in the sequence as it is assembled. One order after another can be started into sequences of zones.

The multiple order, explosion or schedule system: A group of orders is collected and tickets or other indication of the item required to fill the group are prepared and sorted by zone. The items from each zone are isolated and transported to the marshalling area where the items are sorted by order and orders are assembled. The system requires control to ensure that all the items for an order are brought together. Generally, each order is assigned a time at which all items are to arrive in the marshalling area and the position in the area in which they are to be put as they arrive, the material handling system is set up to collect the items from each picking zone on a set time schedule and sent to the right location in the marshalling area.

The area system is the most common system in use since it is simple to manage and control. However, it becomes unwieldy when the number of orders or the number items is large. The zone system is an effort to meet this difficulty by breaking the total order filling system into a series or areas operated in parallel (the zone system) or in sequence (sequential-zone system). When the area system or a modification is merchandised, the capacity of the system is increased to accommodate changes in load. The multiple order or schedule system is better adapted to circumstances where large number of items is managed and a very larger number of small orders, few items per order must be processed. While it is more complex to manage, the schedule system has great flexibility and capability to expand or contract with load variations.

Seven principles of World-Class Warehousing: According to Frazelle (1996), the cost of warehousing accounts to approximately 2% to 5% of the cost of sales of a company. Taking into account that there has been renewed interest and emphasis on achieving return on assets and reducing the cost of warehousing, the need exists to look at certain world-class principles of warehousing. These are the principles that separate world-class warehouse operations from middle-class operations and no-class operations. These principles are common denominators in running successful operations. They are:

Profile: Order profiles, item activity profiles and planning profiles must be analysed to identify the main causes for the downfall of processes and breakthrough opportunities need to be created and maintained (Frazelle, 1996). This means in essence that: "you cannot manage what you do not measure" (Lambert *et al.*, 1998).

Benchmark: Warehouse performance, practices and the operating infrastructure need to be benchmarked against world-class standards to determine the gaps. This will also aid in quantifying the opportunities for improvement. Therefore, estimation can be made of the basic capital requirements for new materials handling equipment and information handling systems that will be needed (Frazelle, 1996).

Simplify: The warehouse processes need to be kept as simple as possible to eliminate the work content. If the need arises to redesign anything, the focus should be on the two activities that are responsible for taking up most of the time: material and information handling (Frazelle, 1996).

Computerize: Warehouse management systems should systematically be justified and implemented together with the concept of paperless warehousing and decision support tools. The tools will maintain the warehouse activity profile, track the warehouse performance, resource utilization and enforce the simplified warehouse processes. Up to date data and actual customer sales data will assist in achieving better inventory performance (Lambert *et al.*, 1998).

Mechanize: The same systematic approach should be followed to justify and implement mechanized handling and storage systems. The systems will ensure that improvements in volume throughput and storage density are obtained, and will assist the warehouse operators in difficult material handling activities (Frazelle, 1996).

Layout: Plan the layout of the warehouse processes, material handling and storage systems in such a way that it ensures a smooth flow of material and information between processes and maximizes floor space (Mulcahy, 1994).

Humanize: Involving the relevant parties and developing team and individual performance goals can humanize the warehouse operations. Ergonomic improvements also need to be implemented in every manual activity in the warehouse (Frazelle, 1996).

3.5 Development of decision support system for selection of manufacturing systems

The development of the economy of any country is supported by the growth of its manufacturing industries. The excellence of manufacturing facilities and continuous improvement play a key role in the progress of any nation. Currently, the manufacturing industries are passing through very tough competition. The economic environment is becoming harsh. In order to survive every industry has to strive for improving productivity in all spheres of activities. What is required is, new ways of improving manufacturing performance by optimally utilising the resources. In this context, World-class manufacturing systems (WCMS) provide an organisation a significant competitive edge over its rivals. WCMS offer many benefits such as reduced cost, increased quality, improvement in competitive position, lower turnover of staff, and many more. World-class manufacturing (WCM) is a term now widely recognised in manufacturing, covering a wide range of activities. Allen *et al.*, (1998) observed World-class manufacturing (WCM) as a popular philosophy of manufacturing reform calling for the adoption of organisational practices that significantly alter coordination within and between manufacturing firms. Kanter (1995) opined that being a WCM organization means its ability to compete on a global basis. Defilippo (1997) stressed upon the customer as a primary focus of WCM, and defined WCM as a method of organising people and equipment to maximise customer satisfaction while minimising the resources required. Mahadevan (1998) commented that for WCM organisations, any activity that finds some usefulness for the final customer is value added and all others are non-value added. Toone (1999) observed that (WCM) is a concept of what a manufacturing needs to be, or to do, in order to be capable of competing with any other organization in its field worldwide. Giffi *et al.* (1990) also pointed out that to WCM, customers and quality aspects are the focal points. Labib (1998) remarked that world-class is a tool used to search for and allow a company to perform at a best-on-class level. Nandi and Banwet (2000) commented that WCM refers to a level of manufacturing excellence that enables a manufacturer to compete with a global player. Yamashina (2000) reported the basic requirements for WCM as: to be outstanding in applied research, production technology, improvement capability, and detailed shop-floor production know-how, compared with its world competitors; and to integrate them as a system. Greene (1991) outlined a more thorough definition for WCM organizations are those companies, which continuously outperform the industry's global best practices, and which know intimately their customers and suppliers, know their competitors' performance capabilities and know their own strengths and weaknesses. All of which form a basis of – continually changing – competitive strategies and performance objectives. Gilgeous and Gilgeous (1999) quoted Peter Urban's definition: The world class manufacturer differs from an average manufacturer in his continuous striving for improvements in quality, cost, lead-times, customer service, and general responsiveness. According to Gunn (1987), WCM rests on three pillars: computer-integrated manufacturing (CIM), total quality control (TQC) and just-in-time (JIT) production methods. These are three fundamental approaches in the modern manufacturing, which may enable a manufacturer to gain competitive advantage for reaching World-Class status. But, according to Maskell (1991, 1994), World-class manufacturing generally includes: a new approach to product quality, just-in-time (JIT) production techniques, change in the way the workforce is managed, a flexible approach to customer requirements. In terms of quality, the World-class manufacturing approach emphasises on the resolution of the problems that causes poor quality, rather than mere detection of those problems. Industry week conducted a survey of American plants to identify which of them are World-class (Kinni, 1996). Where as the questionnaire for this survey was a very detailed one, the characteristics for world-class manufacturing are identified by the three core strategies: customer focus, quality and agility (i.e. the ability to quickly, efficiently and effectively respond to change). Ohno's definition of World-class manufacturing (Japan management Association, 1986) is simple: all we are doing is looking at the time line from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time line by reducing that time line by removing the non-value added wastes. Krar and Gill (2002) commented that the successful world-class manufacturers of the future will be those who are leaders in introducing advanced technologies as quickly as possible. They will also be those who develop a clear goal or target, manage their human resource as well, and develop a strong management team. World-class manufacturers are those that are the first to ask themselves: where do we expect the company to be five years from today? Can we still maintain our competitive edge and compete effectively in cost and product quality if we do not use advanced manufacturing processes and tools? If we do not use the new technology and our competitors anywhere in the world do, what effect it has on our present customers and world markets? Harrison (1988) remarked that there is a common problem to attempts to define the concept of World-class manufacturing that is how to interpret the measures within the operating context of the firm. Sahay *et al.* (2000) opined that the mission of World-class manufacturing is to bring manufacturing closer to the market by eliminating waste.

One school of thought concerning selection of advanced manufacturing systems states that if manufacturing system is to be a competitive tool, selection has to become more of a policy decision rather than an accounting or financial procedure. Another school of thought concerning selection of advanced manufacturing systems states that advanced manufacturing systems can be 'sold' to top-level management only if all relevant costs and benefits are quantified and presented in an easy-to-understand format. Managers, who are considering the introduction of World-class manufacturing focus, quality and agility (i.e. the ability to quickly, efficiently and effectively respond to change). Ohno's definition of World-class manufacturing (Japan management Association, 1986) is simple: all we are doing is looking at the time line from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time line by reducing that time line by removing the non-value added wastes. Krar and Gill (2002) commented that the successful world-class manufacturers of the future will be those who are leaders in introducing advanced technologies as quickly as possible. They will also be those who develop a clear goal or target, manage their human resource as well, and develop a strong management team. World-class manufacturers are those that are the first to ask themselves: where do we expect the company to be five years from today? Can we still maintain our competitive edge and compete effectively in cost and product quality if we do not use advanced manufacturing processes and tools? If we do not use the new technology and our competitors anywhere in the world do, what effect it has on our present customers and world markets? Harrison (1988) remarked that there is a common problem to attempts to define the concept of World-class manufacturing that is how to interpret the measures within the operating context of the firm. Sahay *et al.* (2000) opined that the mission of World-class manufacturing is to bring manufacturing closer to the market by eliminating waste.

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3.5.1 Development of analytical binary model for selection of manufacturing systems

The "weighted attributes" method is used in the selection of manufacturing systems. The major problems with this method are: the simultaneous assignment of weight values to all attributes, the difficulty of quantifying performances of attributes and the insertion of value judgements after the evaluation process has started. The binary decision method is discussed in the literature (Marazzi, 1985 and Miles, 1972). Here analytical binary model (ABM) is developed for selection of manufacturing systems. The schematic of ABM for selection of manufacturing systems is shown in Figure 3.28.

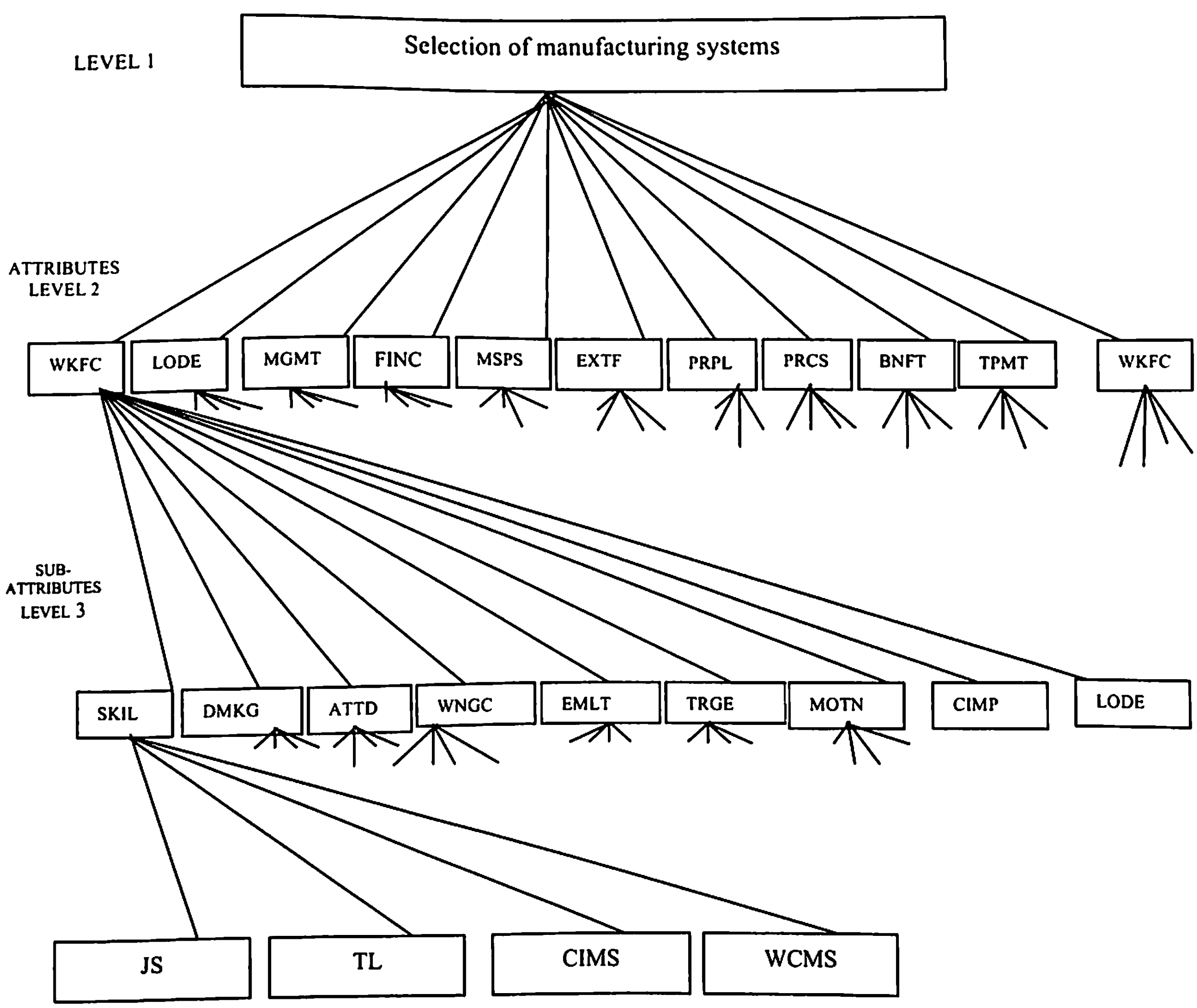


Figure 3.28: Schematic of analytical binary model for selection of manufacturing systems

3.5.1.1 Algorithm

Step 1. Determine the main attributes/criteria and sub-attributes/criteria in each main attribute/criteria that govern the problem. The attributes and sub-attributes for selection of manufacturing systems are:

Workforce [WKFC]

- Skill [SKIL]
- Decision-making [DMKG]
- Attitude [ATTD]
- Willingness to change [WNGC]
- Employment [EMLT]
- Training and education [TRGE]
- Motivation [MOTN]
- Continuous improvement [CIMP]
- Loyalty and dedication [LODE]

Organization [ORGN]

- Organization levels and structure [OLST]
- Growth orientation [GORN]
- Vigilance [VIGL]
- Commitment to technology [COMT]
- Acceptance of risks [ACCR]
- Cross-functional co-operation/co-ordination [CFCO]
- Receptivity [RCPT]
- Slack [SLCK]

- Adaptability [ADPT]
- Diverse range of skills [DRSK]

Management [MGMT]

- Professionalization [PROF]
- Universality [UVRS]
- Responsibilities [RESP]
- Strategic management [SMGT]
- Empowerment [EMPR]
- Human resource management [HNRM]
- Continuous improvement [CNTI]
- Cross functional team management [CFTM]

Finance [FINC]

- Kinds of capital [KNDC]
- Sources of capital [SOCP]
- Financial statements [FNST]
- Risk and insurance [RSKI]
- Budget and financial control [BFCO]

Marketing [MRKT]

- Market selection and product selection [MSPS]
- Entry strategy/basic routes for marketing [ESBR]
- Selection of distribution channels [SDCH]
- Development of pricing strategy for markets [DPST]
- Marketing research [MKTR]
- Marketing communication [MKTC]

- Mastering the procedural complexities [MSPC]
- Organizational adaptations [ORAD]

External factors [EXTF]

- Economic dimension [ECOD]
- Social dimension [SODM]
- Political dimension [PODM]
- Technology dimension [TCDM]
- Regulatory dimension [RGDM]
- Competitive dimension [CMDM]

Product planning [PRPL]

- Range of products offered [RGPO]
- Range of products at different stages of their life cycle [RPDL]
- Product strategy [PRST]
- New product development [NWPD]
- Evaluation of products [EVPR]
- Technology management [TMNT]

Processes [PRCS]

- Processing Technologies [PRTH]
- Quality tools/management [QLTM]
- Production modes/layout styles [PMLS]
- Type of processes [TOPR]
- Smoothing work flows [SMWF]
- Setup operations [SOPR]

Benefits	[BNFT]
• Improvement in productivity	[IMPR]
• Improvement in quality	[IMQL]
• Improvement in profit margin	[IMPM]
• Improvement in competitive position	[IMCP]
• Improvement in potential human benefits	[IPHB]
• Improvement in delivery and customer service	[IDCS]
• Improvement in flexibility	[IMFL]
• Reduction in inventory	[RDIN]
• Reduction in cost	[RDCT]
Manufacturing management procedures	[MMGP]
• Total productive maintenance	[TPMT]
• Total quality management	[TQMT]
• Just-in-time	[JITM]
• Manufacturing strategy	[MFGS]
• Supply chain management	[SCMT]
• Lean manufacturing	[LNMF]
• Continuous improvement	[CTIM]
• Manufacturing planning and control	[MPLC]

The alternative manufacturing systems considered are:

Job Shop	JS
Transfer line	TL
Computer integrated manufacturing systems	CIMS
World-class manufacturing systems	WCMS

Step 2: A n×n decision matrix is drawn in which n represents the number of attributes. Here, ten attributes are considered relevant, and the decision matrix is shown below in table 3.33. Each attribute is compared to each other attribute and the relative importance of attributes over one another in the form of simple binary decision of the type "better/worse" or "greater/smaller" (Maccrimmon, 1968) is represented in decision matrix.

Table 3.33: Decision matrix showing weightages and normalized weightages of attributes

	WKFC	ORGN	MGMT	FINC	MRKT	EXTF	PRPL	PRCS	BNFT	MMGP	Weightage	Normalized Wt.
WKFC	0	1	0	1	1	0	1	1	0	1	6	0.1333
ORGN	0	0	1	0	1	0	0	1	1	1	5	0.1111
MGMT	1	0	0	0	1	0	0	1	1	1	5	0.1111
FINC	0	1	1	0	1	1	0	0	1	1	6	0.1333
MRKT	0	0	0	0	0	0	1	1	0	1	3	0.0667
EXTF	1	1	1	0	1	0	0	1	1	0	6	0.1333
PRPL	0	1	1	1	0	1	0	1	0	0	5	0.1111
PRCS	0	0	0	1	0	0	0	0	0	1	2	0.0444
BNFT	1	0	0	0	1	0	1	1	0	1	5	0.1111
MMGP	0	0	0	0	0	1	1	0	0	0	2	0.0444

Step 3 A decision matrix is formed for each attribute (i=1, 2, 3--------, n) considering its corresponding sub-attributes (j=1, 2, 3------------, m). Here, in table 3.34, a square matrix shows sub-attributes of main attribute 'WKFC'. The matrix shows weightages and normalized emphasis coefficients E_{ji} of all sub attributes. The coefficients are the normalized values of the sum of each row of each decision matrix.

Table 3.34: Decision matrix for sub attributes of 'WKFC'

	SKIL	DMKG	ATTD	WNGC	EMLT	TRGE	MOTN	CIMP	LODE	Weightage	Emphasis Coe.
SKIL	0	1	0	1	1	1	0	0	1	5	0.1389
DMKG	0	0	1	1	0	0	1	0	1	4	0.1111
ATTD	1	0	0	0	1	0	1	1	0	4	0.1111
WNGC	0	0	1	0	0	1	1	0	1	4	0.1111
EMLT	0	1	0	1	0	0	0	1	1	4	0.1111
TRGE	0	1	1	0	1	0	0	1	0	4	0.1111
MOTN	1	0	0	0	1	1	0	1	0	4	0.1111
CIMP	1	1	0	1	0	0	0	0	1	4	0.1111
LODE	0	0	1	0	0	1	1	0	0	3	0.0833

Step4 Similarly, calculation of performance of alternatives for sub-attribute is carried out. The sample calculation of performance of alternatives for sub-attribute 'SKIL' is shown in table 3.35. Table 3.36 shows the summary of steps 2-4.

Table 3.35: Performance of alternative manufacturing systems for attribute 'SKIL'

	JS	TL	CIMS	WCMS	Weightages	Emphasis Coe.
JS	0	0	0	0	0	0
TL	1	0	0	0	1	0.1667
CIMS	1	1	0	1	3	0.5
WCMS	1	1	0	0	2	0.3333

Table 3.36: Weightages of attributes for alternatives

	Lt-3	Lt-2	JS	TL	CIMS	WCMS
SKIL	0.1389	0.1333	0.0000	0.1667	0.5	0.3333
DMKG	0.1111	0.1333	0.0000	0.1667	0.5	0.3333
ATTD	0.1111	0.1333	0.0000	0.3333	0.1667	0.5
WNGC	0.1111	0.1333	0.0000	0.3333	0.3333	0.3333
EMLT	0.1111	0.1333	0.0000	0.1667	0.3333	0.5
TRGE	0.1111	0.1333	0.0000	0.1667	0.3333	0.5
MOTN	0.1111	0.1333	0.0000	0.1667	0.3333	0.5
CIMP	0.1111	0.1333	0.0000	0.1667	0.3333	0.5
LODE	0.1111	0.1333	0.0000	0.3333	0.1667	0.5
OLST	0.1111	0.1111	0.1667	0.1667	0.1667	0.5
GORN	0.0889	0.1111	0.1667	0.1667	0.1667	0.5
VIGL	0.1111	0.1111	0.1667	0.0000	0.3333	0.5
COMT	0.1333	0.1111	0.1667	0.1667	0.1667	0.5
ACCR	0.1111	0.1111	0.1667	0.1667	0.1667	0.5
CFCO	0.1111	0.1111	0.0000	0.3333	0.1667	0.5
RCPT	0.0667	0.1111	0.1667	0.1667	0.1667	0.5
SLCK	0.0667	0.1111	0.1667	0.1667	0.1667	0.5
ADPT	0.0889	0.1111	0.1667	0.1667	0.1667	0.5
DRSK	0.1111	0.1111	0.1667	0.1667	0.1667	0.5
PROF	0.1786	0.1111	0.1667	0.1667	0.1667	0.5
UVRS	0.1429	0.1111	0.1667	0.1667	0.1667	0.5
RESP	0.0714	0.1111	0.1667	0.1667	0.1667	0.5

SMGT	0.1429	0.1111	0.1667	0.1667	0.1667	0.5
EMPR	0.0714	0.1111	0.1667	0.1667	0.1667	0.5
HNRM	0.0714	0.1111	0.1667	0.1667	0.1667	0.5
CNTI	0.2143	0.1111	0.1667	0.1667	0.1667	0.5
CFTM	0.1071	0.1111	0.1667	0.1667	0.1667	0.5
KNDC	0.3	0.1333	0.1667	0.1667	0.1667	0.5
SOCP	0.0000	0.1333	0.1667	0.0000	0.3333	0.5
FNST	0.3	0.1333	0.1667	0.1667	0.1667	0.5
RSKI	0.3	0.1333	0.1667	0.0000	0.3333	0.5
BFCO	0.1	0.1333	0.1667	0.1667	0.1667	0.5
MSPS	0.1427	0.0667	0.0000	0.3333	0.3333	0.3333
ESBR	0.1427	0.0667	0.1667	0.1667	0.1667	0.5
SDCH	0.1071	0.0667	0.1667	0.1667	0.3333	0.3333
DPST	0.1786	0.0667	0.1667	0.1667	0.3333	0.3333
MKTR	0.1429	0.0667	0.1667	0.1667	0.1667	0.5
MKTC	0.0357	0.0667	0.1667	0.0000	0.5	0.3333
MSPC	0.0357	0.0667	0.1667	0.0000	0.5	0.3333
ORAD	0.2143	0.0667	0.1667	0.0000	0.3333	0.5
ECOD	0.2667	0.1333	0.1667	0.1667	0.3333	0.3333
SODM	0.0667	0.1333	0.1667	0.0000	0.3333	0.5
PODM	0.2	0.1333	0.1667	0.0000	0.3333	0.5
TCDM	0.1333	0.1333	0.1667	0.0000	0.5	0.3333
RGDM	0.1333	0.1333	0.0000	0.3333	0.3333	0.3333
CMDM	0.2000	0.1333	0.1667	0.1667	0.3333	0.3333
RGPO	0.2	0.1111	0.1667	0.1667	0.1667	0.5
RPDL	0.2	0.1111	0.1667	0.1667	0.1667	0.5
PRST	0.2	0.1111	0.0000	0.3333	0.1667	0.5
NWPD	0.1333	0.1111	0.3333	0.1667	0.0000	0.5
EVPR	0.2	0.1111	0.1667	0.1667	0.3333	0.3333
TMNT	0.0667	0.1111	0.3333	0.1667	0.0000	0.5
PRTH	0.2	0.0444	0.3333	0.1667	0.0000	0.5
QLTM	0.1333	0.0444	0.3333	0.1667	0.0000	0.5
PMLS	0.1333	0.0444	0.3333	0.1667	0.0000	0.5
TOPR	0.2667	0.0444	0.3333	0.1667	0.0000	0.5
SMWF	0.2	0.0444	0.1667	0.0000	0.3333	0.5
SOPR	0.0667	0.0444	0.1667	0.0000	0.3333	0.5
IMPR	0.1111	0.1111	0.1667	0.1667	0.1667	0.5
IMQL	0.1389	0.1111	0.1667	0.1667	0.1667	0.5
IMPM	0.1389	0.1111	0.0000	0.1667	0.3333	0.5

IMCP	0.1111	0.1111	0.0000	0.3333	0.1667	0.5
IPHB	0.1389	0.1111	0.1667	0.1667	0.1667	0.5
IDCS	0.0556	0.1111	0.0000	0.3333	0.1667	0.5
IMFL	0.0556	0.1111	0.0000	0.3333	0.1667	0.5
RDIN	0.1389	0.1111	0.1667	0.1667	0.1667	0.5
RDCT	0.1111	0.1111	0.0000	0.3333	0.1667	0.5
TPMT	0.1429	0.0444	0.1667	0.0000	0.3333	0.5
TQMT	0.0714	0.0444	0.0000	0.3333	0.1667	0.5
JITM	0.1786	0.0444	0.0000	0.1667	0.3333	0.5
MFGS	0.1071	0.0444	0.1667	0.1667	0.1667	0.5
SCMT	0.1429	0.0444	0.1667	0.1667	0.1667	0.5
LNMF	0.1071	0.0444	0.0000	0.1667	0.5	0.3
CTIM	0.1071	0.0444	0.0000	0.1667	0.5	0.3
MPLC	0.1429	0.0444	0.0000	0.1667	0.5	0.3

Step 5 Next, the figure of merit (FOM) $M(P_j)$ for each sub-attribute P_j is calculated by multiplying each value in 'weight of sub-attribute' column by the respective value of 'attribute weight' column (see table 3.37).

$$M(P_j) = \sum_{i=1}^{i=n} w_i \times E_{ij}$$

The weights w_i of the attributes were obtained in step 2. The emphasis coefficients E_{ij} were obtained in step 4.

Table 3.37: FOM for sub-attribute

Sub-attribute	FOM
SKIL	0.018515
DMKG	0.01481
ATTD	0.01481
WNGC	0.01481
EMLT	0.01481
TRGE	0.01481
MOTN	0.01481
CIMP	0.01481
LODE	0.01481
OLST	0.012343
GORN	0.009877

VIGL	0.012343
COMT	0.01481
ACCR	0.012343
CFCO	0.012343
RCPT	0.00741
SLCK	0.00741
ADPT	0.009877
DRSK	0.012343
PROF	0.019842
UVRS	0.015876
RESP	0.007933
SMGT	0.015876
EMPR	0.007933
HNRM	0.007933
CNTI	0.023809
CFTM	0.011899
KNDC	0.03999
SOCP	0
FNST	0.03999
RSKI	0.03999
BFCO	0.01333
MSPS	0.009518
ESBR	0.009518
SDCH	0.007144
DPST	0.011913
MKTR	0.009531
MKTC	0.002381
MSPC	0.002381
ORAD	0.014294
ECOD	0.035551
SODM	0.008891
PODM	0.02666
TCDM	0.017769
RGDM	0.017769
CMDM	0.02666
RGPO	0.02222
RPDL	0.02222
PRST	0.02222
NWPD	0.01481

EVPR	0.02222
TMNT	0.00741
PRTH	0.00888
QLTM	0.005919
PMLS	0.005919
TOPR	0.011841
SMWF	0.00888
SOPR	0.002961
IMPR	0.012343
IMQL	0.015432
IMPM	0.015432
IMCP	0.012343
IPHB	0.015432
IDCS	0.006177
IMFL	0.006177
RDIN	0.015432
RDCT	0.012343
TPMT	0.006345
TQMT	0.00317
JITM	0.00793
MFGS	0.004755
SCMT	0.006345
LNMF	0.004755
CTIM	0.004755
MPLC	0.006345

Step 6. Multiply emphasis coefficients of alternative with FOM for sub-attribute and summing the results. This is shown in table 3.38 and table 3.39.

Table 3.38: Figure of merit for alternatives

	JS	TL	CIMS	WCMS
SKIL	0.0000	0.003087	0.009258	0.006171
DMKG	0.0000	0.002469	0.007405	0.004936
ATTD	0.0000	0.004936	0.002469	0.007405
WNGC	0.0000	0.004936	0.004936	0.004936
EMLT	0.0000	0.002469	0.004936	0.007405
TRGE	0.0000	0.002469	0.004936	0.007405
MOTN	0.0000	0.002469	0.004936	0.007405
CIMP	0.0000	0.002469	0.004936	0.007405

LODE	0.0000	0.004936	0.002469	0.007405
OLST	0.002058	0.002058	0.002058	0.006172
GORN	0.001646	0.001646	0.001646	0.004938
VIGL	0.002058	0.0000	0.004114	0.006172
COMT	0.002469	0.002469	0.002469	0.007405
ACCR	0.002058	0.002058	0.002058	0.006172
CFCO	0.0000	0.004114	0.002058	0.006172
RCPT	0.001235	0.001235	0.001235	0.003705
SLCK	0.001235	0.001235	0.001235	0.003705
ADPT	0.001646	0.001646	0.001646	0.004938
DRSK	0.002058	0.002058	0.002058	0.006172
PROF	0.003308	0.003308	0.003308	0.009921
UVRS	0.002647	0.002647	0.002647	0.007938
RESP	0.001322	0.001322	0.001322	0.003966
SMGT	0.002647	0.002647	0.002647	0.007938
EMPR	0.001322	0.001322	0.001322	0.003966
HNRM	0.001322	0.001322	0.001322	0.003966
CNTI	0.003969	0.003969	0.003969	0.011904
CFTM	0.001984	0.001984	0.001984	0.005949
KNDC	0.006666	0.006666	0.006666	0.019995
SOCP	0.0000	0.0000	0.0000	0.0000
FNST	0.006666	0.006666	0.006666	0.019995
RSKI	0.006666	0.0000	0.013329	0.019995
BFCO	0.002222	0.002222	0.002222	0.006665
MSPS	0.0000	0.003172	0.003172	0.003172
ESBR	0.001587	0.001587	0.001587	0.004759
SDCH	0.001191	0.001191	0.002381	0.002381
DPST	0.001986	0.001986	0.00397	0.00397
MKTR	0.001589	0.001589	0.001589	0.004766
MKTC	0.000397	0.0000	0.001191	0.000794
MSPC	0.000397	0.0000	0.001191	0.000794
ORAD	0.002383	0.0000	0.004764	0.007147
ECOD	0.005926	0.005926	0.011849	0.011849
SODM	0.001482	0.0000	0.002963	0.004446
PODM	0.004444	0.0000	0.008886	0.01333
TCDM	0.002962	0.0000	0.008884	0.005922
RGDM	0.0000	0.005922	0.005922	0.005922
CMDM	0.004444	0.004444	0.008886	0.008886
RGPO	0.003704	0.003704	0.003704	0.01111

RPDL	0.003704	0.003704	0.003704	0.01111
PRST	0.0000	0.007406	0.003704	0.01111
NWPD	0.004936	0.002469	0.0000	0.007405
EVPR	0.003704	0.003704	0.007406	0.007406
TMNT	0.00247	0.001235	0.0000	0.003705
PRTH	0.00296	0.00148	0.0000	0.00444
QLTM	0.001973	0.000987	0.0000	0.002959
PMLS	0.001973	0.000987	0.0000	0.002959
TOPR	0.003947	0.001974	0.0000	0.005921
SMWF	0.00148	0.0000	0.00296	0.00444
SOPR	0.000494	0.0000	0.000987	0.001481
IMPR	0.002058	0.002058	0.002058	0.006172
IMQL	0.002572	0.002572	0.002572	0.007716
IMPM	0.0000	0.002572	0.005143	0.007716
IMCP	0.0000	0.004114	0.002058	0.006172
IPHB	0.002572	0.002572	0.002572	0.007716
IDCS	0.0000	0.002059	0.00103	0.003089
IMFL	0.0000	0.002059	0.00103	0.003089
RDIN	0.002572	0.002572	0.002572	0.007716
RDCT	0.0000	0.004114	0.002058	0.006172
TPMT	0.001058	0.0000	0.002115	0.003172
TQMT	0.0000	0.001057	0.000528	0.001585
JITM	0.0000	0.001322	0.002643	0.003965
MFGS	0.000793	0.000793	0.000793	0.002378
SCMT	0.001058	0.001058	0.001058	0.003172
LNMF	0.0000	0.000793	0.002378	0.001427
CTIM	0.0000	0.000793	0.002378	0.001427
MPLC	0.0000	0.001058	0.003172	0.001903
Total	0.130019	0.167865	0.240119	0.464991

Table 3.39: Decision index for the desirability of each alternative

Decision Index of Job Shop	0.130019
Decision Index of Transfer Line	0.167865
Decision Index of CIMS	0.240119
Decision Index of WCMS	**0.464991**

The best alternative is WCMS. Therefore selection of WCMS is justified.

3.5.1.2 Validation

Highly user-friendly software, for the analytical binary model is developed in VC++ to aid the user for pair-wise comparison of the attributes as well as for the alternatives and for analysing the user inputs. The reliability of the judgements supplied by the user can be estimated from the graphs (figure 3.29-32) that are generated for each alternative and its corresponding deciding criteria.

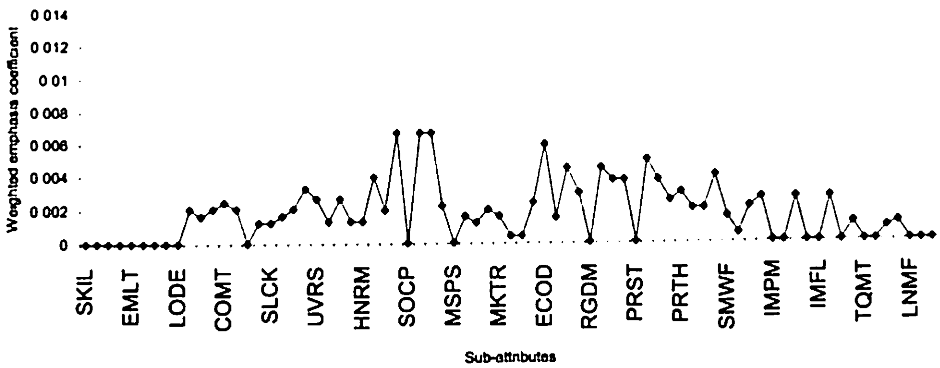


Figure 3.29: Data summary graph for alternative: JS

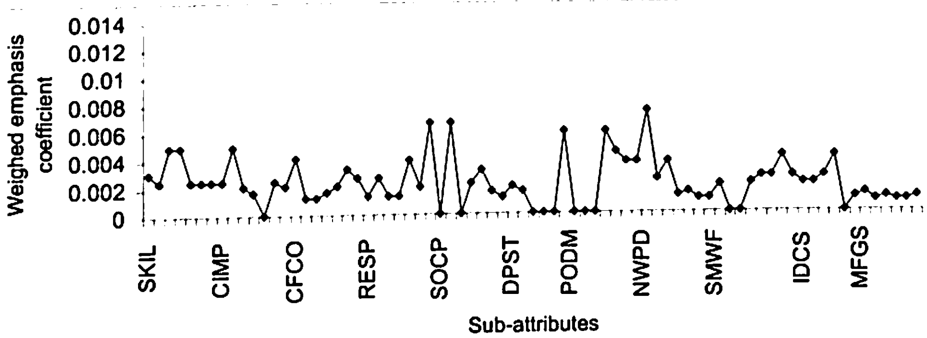


Figure 3.30: Data summary graph for alternative: TL

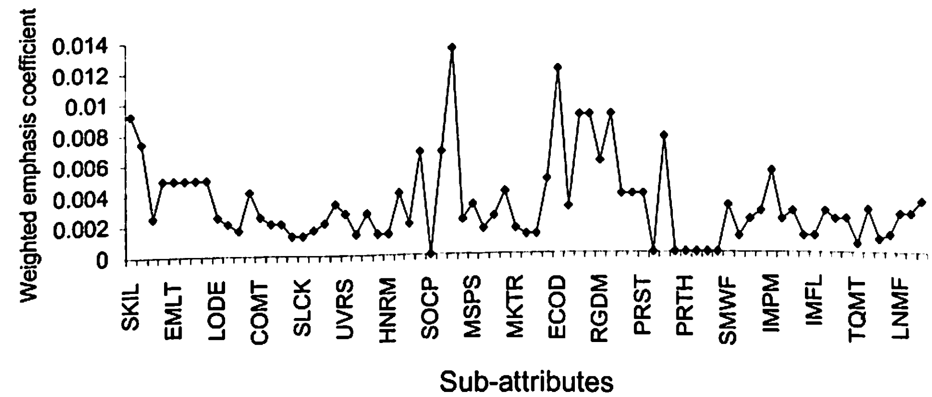


Figure 3.31: Data summary graph for alternative: CIMS

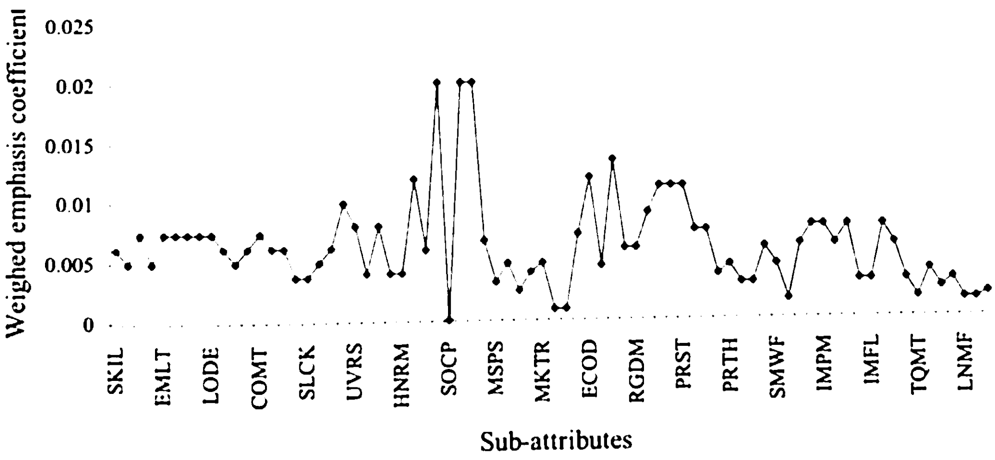


Figure 3.32: Data summary for alternative: WCMS

It is very clear from the table 3.39 and figures 3.29–3.32 above that the World-class manufacturing systems are the best manufacturing systems among the available alternatives. Therefore, the selection of WCMS is justified.

3.6 Conclusions

In this chapter, decision support systems are developed for design of facilities driver in supply chain management. The facilities driver consists the decisions regrading location, capacity, warehouse methodology and manufacturing systems. Decision support system i.e. performance value analysis model is developed for the selection of facilities location. One case situation is elucidated in order to reinforce the salient features of the concept. Also a decision support system framework is developed for selection of facilities location considering benefit/cost-ratios of the potential feasible locations. The proposed framework is evaluated by a case situation but it can be applicable to different types of industries by allowing managers to structure their unique problems into priority weights, which can reflect their own priority considerations. For capacity decision, decision support system framework is developed which considers both priority of alternative locations and related cost along the supply chain. Simulated annealing algorithm is developed for solving this multi-objective problem. The AHP model is developed for determination of the priority value for alternative locations. The proposed framework is validated by a case situation to reinforce the salient features of the concept. The decision support system framework is developed for selection of warehouse methodology. The framework consists of constant sum model for determination of the priority value for feasible locations, integer programming for optimal number and capacity of warehouses, size of the warehouse and internal warehouse management. One case situation is elucidated in order to reinforce the salient features of the concept. For manufacturing systems, analytical binary model is developed for selection of manufacturing systems and concluded World-class manufacturing systems are better compared to other manufacturing systems. One case situation is elucidated in order to reinforce the salient features of the concept.

References

[1] ABIDO, M. A. (2000), "Robust design of multi-machine power system stabilizers using simulated annealing", *IEEE Transaction on Energy Conversion*, vol. 15, no. 3, pp. 297-304.

[2] ACKERMAN, K. B. (1997), Practical Handbook of Warehousing, International Thomson Publishing, fourth edition New York.

[3] ADIL, G. K., RAJAMNI, D. and STRONG, D. (1997), "Assignment allocation and simulated annealing algorithms for cell formulation", *IIE Transactions*, pp. 53-67.

[4] ALLEN, J., BAKOS, Y., and KLING, R. (1998), "Sustaining new coordination methods: The case of World Class Manufacturing", Working paper, *Centre for Social Informatics*, Indiana University, USA. Available http://www.slis.indiana.edu/csi/wp/.

[5] AMADOR, R. and STARBIRD, S. (1989), "The evaluation of international agribusiness investment locations using multidimensional scaling", *Regional Science and Urban Planning*, vol. 5, pp. 139-151.

[6] APPLEBAUM, W. (1968), The Analog Method for Estimating Potential Store Sales, Guide to Store Location Research, Addison-Wesley, Reading, M.A.

[7] ATTHIRAWONG, W. and MACCARTHY, B. (2000), "Factors affecting international location/allocation decisions: can we structure them?", *Proceedings of the 5th International Manufacturing Research Symposium*, pp. 1-8.

[8] ATTHIRAWONG, W. and MACCARTHY, B. (2001), "Identification of the location pattern of manufacturing plants in Thailand", *Proceedings of the 6th International Manufacturing Research Symposium*, pp.1-13. Cambridge, UK.

[9] BADRI, M. A. (1996), "Multi-criteria approach to global facility location-allocation problem", *Information and Management Science*, vol. 7, no. 3, pp. 1-9.

[10] BADRI, M. A. (1999), "Combining the analytic hierarchy process and goal programming for global facility location—allocation problem", *International Journal of Production Economics*, vol. 62, no. 3, pp. 237–248.

[11] BADRI, M. A. and DAVIS, D. (1995), "Decision support models for the location of firms in industrial sites", *International Journal of Operations and Production Management*, vol. 15, no. 1, pp. 50-62.

[12] BADRI, M.A. (1999), "Combining the analytical hierarchy process and goal programming for global facility location-allocation problem", *International Journal of Production Economics*, vol. 62, no. 2, pp. 237-248.

[13] BALDACCI, R., HADJICONSTANTINOU, E., MANIEZZO, V. and MINGOZZI, A. (2002), "A new method for solving capacitated location problems based on a set partitioning approach", *Computers and Operations Research*, vol .29, pp. 365-386.

[14] BARDA, O. H., JOSEPH. D. and PIERRE, L. (1990), "Multi-criteria location of thermal power plants", *European Journal of Operational Research*, vol. 45, pp. 332-368.

[15] BARKLEY, D. and McNAMARA, K. (1994), "Manufacturer's location decisions: do surveys provide helpful insight?", *International Regional Science Review*, vol. 17, no. 1, pp. 23-47.

[16] BASS, B.M., MCGREGOR, D.W. and WALTERS, J. L. (1977), "Selecting foreign plant sites: economic, social, and political considerations", *Academy of Management Journal*, vol. 20, no. 4, pp. 535-51.

[17] BASSAN, J., ROLL, Y. and ROSENBLATT, M. J. (1980), "Internal layout design of a warehouse", *AIIE Transactions*, vol 12, no 4, pp. 317-322.

[18] BAUMOL, W. and WOLFE, P. (1958), "A warehouse location problem", *Operations Research*, vol. 6, no. 2, pp. 252-263.

[19] BEASLEY, J. E. (1988), "An algorithm for solving large capacitated warehouse location problems", *European Journal of Operation Research*, Vol 33, pp 314–25.

[20] BEAUJON, G. J., MARIN, S. P. and MCDONALD, G. C. (2001) "Balancing and optimizing a portfolio of R&D project selection and termination", *Naval Research Logistics*, vol. 48, no.1, pp. 18-40.

[21] BENJAMIN, C. O., CHI, S. C., GABER, T. and RIORDAN C. A. (1995), "Comparing BP and ART II neural network classifiers for facility location", *Computers and Industrial Engineering*, vol. 28, no. 1, pp. 43–50.

[22] BERMAN, O., DREZNER, Z. and WESOLOWSKY, G. O. (2001), "Location of facilities on a network with groups of demand points", *IIE Transactions*, vol. 33, no. 8, pp.637–648.

[23] BESSANT, J. (1993), "The lesson of failure: learning to manage new manufacturing technologies", *International Journal of Technology Management*, vol. 8, pp. 197-215.

[24] BLOOMBERG, D. J., LEMAY, S. and HANNA, J. B. (2002), Logistics, Prentice-Hall Inc, New Jersey.

[25] BOADEN, R. and DALE, B. (1990), "Justification of computer integrated manufacturing: some insights into the practice", *IEEE Transactions on Engineering Management*, vol. 37, no. 4, pp. 291-296.

[26] BOER, H., HILL, M., and KRABBENDAM, K. (1990), "FMS implementation management: promise and performance", *International Journal of Operations and Production Management*, vol. 10, no. 1, pp. 5-20.

[27] BOWERSOX, D. J. and CLOSS, D. J. (1996), Logistical Management, McGraw-Hill, New York.

[28] BOYER, K., LEONG, G., WARD, P., and KRAJEWSKI, L. (1997), "Unlocking the potential of advanced manufacturing technologies", *Journal of Operations Management*, vol. 15, no. 4, pp. 331-347.

[29] BRAMEL J and SIMCHI-LEVI D., (1997), The Logic of Logistic, Springer Series in Operation Research.

[30] BRANDEAU, M. and CHIU, S. (1989), "An overview of representative problems in location research", *Management Science*, vol. 35, no. 6, pp. 645-674.

[31] BROUCHER, T., LUXHOJ, J., DESCOVICH, T., and LITMAN, N. (1993), "Multicriteria evaluation of automated filling systems: a case study", *Journal of Manufacturing Systems*, vol. 12, no. 5, pp. 357-378.

[32] BRUSH, T. H., MARITAN, C. A. and KARNANI, A. (1999), "The plant location decision in multinational manufacturing firms: an empirical analysis of international business and manufacturing strategy perspectives", *Production and Operations Management*, vol. 8, no. 2, pp. 109-132.

[33] BURNHAM, J. (1994), Integrated Facilities Management, Irwin, Burr Ridge.

[34] BUTT, S. E. and CAVALIER, T. M. (1996), "Efficient algorithm for facility location in the presence of forbidden regions", *European Journal of Operational Research*, vol. 90, no. 1, pp. 56–70.

[35] CANADA, J. (1986), "Annotated bibliography on justification of computer integrated manufacturing systems", *The Engineering Economists*, vol., 31, no. 2, pp. 137-150.

[36] CANADA, J. and SULLIVAN, W. (1990), "Persistent pitfalls and applicable approaches for justification of advanced manufacturing systems", *Engineering Costs and Production Economics*, vol. 18, no. 3, pp. 247-253.

[37] CANEL, C. and DAS, S. R. (2002), "Modeling global facility location decisions: integrating marketing and manufacturing decisions", *Industrial Management and Data Systems*, vol. 102, no. 2, pp. 110-118.

[38] CANEL, C. and KHUMAWALA, B. (1996), "A mixed-integer programming approach for the international facilities location problem", *International Journal of Operations and Production Management*, vol. 16, no. 4, pp. 49-68.

[39] CANEL, C., KHUMAWALA, B. M., LAW, J. and LOH, A. (2001), "Algorithm for the capacitated, multi-commodity multi-period facility location problem", *Computers and Operations Research*, vol. 28, no. 5, pp. 411– 427.

[40] CARRASCO, H. and LEE, S. (1992), "Economics of advanced manufacturing systems during system design and development", *Economics of Advanced Manufacturing Systems*, edited by H. R. Parsaei and A. Mital, Chapman and Hall, London.

[41] CHAN, I. (2001), "Private vs. Public Warehousing" Available from: http://www.geocities.com./liame/warehousing.htm#Public.

[42] CHANDAN, J., KAWATRA, M., and KIM K. (1996), Essentials of linear programming, Vikas Publications, New Delhi.

[43] CHARNES, A. and COOPER W. (1961), Management models and industrial applications of linear programming, Wiley Publications, NY.

[44] CHASE, R. and AQUILANO, N. (1995), Production and Operations Management: Manufacturing and Services, Irwin, Burr Ridge.

[45] CHEN, C. T. (2001), "A fuzzy approach to select the location of the distribution centre", *Fuzzy Sets and Systems*, vol. 118, pp. 65–73.

[46] CHEN, I. and SMALL, M. (1994), "Implementing advanced manufacturing technology: an integrated planning model", *OMEGA International Journal of Management Science*, vol. 22, no. 1.

[47] CHEN, S. M. (2001), "Fuzzy group decision-making for evaluating the rate of aggregative risk in software development", *Fuzzy Sets and Systems*, vol. 118, pp. 75–88.

[48] CHIADAMRONG, N. and O'BRIEN, C. (1999), "Decision support tool for justifying alternative manufacturing and production control systems", *International Journal of Productions Economics*, vol. 60-61, pp. 177-186.

[49] CHOPRA, S. and MEINDL, P. (2003), "Supply chain management: strategy, planning and operation", Pearson Education Asia.

[50] CHRISTO, E. N. and BEASLEY, J. E. (1983), "Extensions to a Lagrangean relaxation approach for the capacitated warehouse location problem" *European Journal of Operation Research*, vol. 12, pp 19–28.

[51] CLOSS, D. J. and THOMPSON, C. K. (1992), "Logistics physical resource management", *Journal of Business Logistic*, vol. 13, no. 2, pp. 269-283.

[52] COELLO, COELLO, C. A. (1999), "A Comprehensive Survey of Evolutionary-Based Multiobjective Optimization Techniques", *Knowledge and Information Systems: An International Journal*, vol. 1, no. 3, pp. 269-308.

[53] COHEN, M. A., and Moon, S., (1991), "An Integrated Plant Loading Model with Economies of Scale and Scope", *European Journal of Operations Research*, vol. 50, pp. 266-279.

[54] COMLEY, W. J. (1995), "Location of ambivalent facilities: use of a quadratic zero-one programming algorithm", *Applied Mathematical Modelling*, vol. 19, no. 1, pp. 26–29.

[55] COOPER, J. (1990), Logistics and Distribution Planning, Kogan Page, London.

[56] COYLE, J. J, BARDI, E. J and LANGLEY C. J. (1996), The Management of Business Logistics, Sixth edition. California: West Publishing Co.

[57] CROWE, T. J., NOBLE, J. S. and MACHIMADA, J. S. (1998), "Multi-attribute analysis of ISO 9000 registration using AHP", *International Journal of Quality and Reliability Management*, vol. 15, no. 2, pp. 205-222.

[58] CURTIN, F. T. (1984a), "New costing methods needed for manufacturing technology", *AMA Forum*, vol. 73, no. 4, pp. 29-34.

[59] CURTIN, F. T. (1984b), "Planning and justifying factory automation systems", *Production Engineering*, vol. 31, no. 5, pp. 46-51.

[60] D'ANGELO A., GASTALDI, M., and LEVIALDI, N. (1996), "Multi-criteria evaluation model for flexible manufacturing system design", *Computer Integrated Manufacturing Systems*, vol. 9 No. 3, pp. 171-178.

[61] D'ANGELO. A., GASTALDI, M., and LEVIALDI, N. (1996), "Dynamic analysis of the performance of a flexible manufacturing system: a real case application", *Computer Integrated Manufacturing Systems*, vol. 7 No. 2, pp. 101-110.

[62] DEAN, J., SUSMAN, G., and PORTER, P. (1990), "Technical, economic and political factors in advanced manufacturing technology implementation", *Journal of Engineering and Technology Management*, vol. 7, pp. 129-144.

[63] DEFILIPPO, J. (1997), "World-class manufacturing in Chengdu: a case study on China's first aviation joint venture", *International Journal of Technology Management*, vol. 13, no. 5/6, pp 681-694.

[64] DEMMEL, J. and ASKIN, R. (1992), "A multiple objective decision model for the evaluation of advanced manufacturing system technologies", *Journal of Manufacturing Systems*, vol. 11, no. 3, pp. 179-194.

[65] DHAVALE, D. (1995), "Justifying manufacturing cells-what to do when conventional cost accounting lets you down", *Manufacturing Engineering*, vol. 115, pp. 31-32.

[66] DILWORTH, J. (1996), Operations Management, McGraw-Hill, NY.

[67] DORNEIR, P., ERNST, R., FENDER, M. and KOUVELLIS, P. (1998), Global Operations and Logistics: Text and Cases, John Wiley and Sons, USA.

[68] DOUGLAS, S. P. and CRAIG, C. S. (1989), "Evolution of global marketing strategy: scale, scope and synergy", *Columbia Journal of World Business*, vol. 24, no. 3, pp. 47-60.

[69] DREZNER, Z. (1995), Facility Location: A Survey of Applications and Methods, Springer Publishers, New York.

[70] DYMSZA, W. A., (1972), Multinational Business Strategy, McGraw-Hill, NY.

[71] EILON, S. (1982), "Multi-criteria warehouse location", *International Journal of Physical Distribution and Materials Management*, Vol. 12 No. 1.

[72] ELIZANDRO, D. (1993), "Economics of advanced manufacturing systems", *Engineering Economist*, vol. 38, no. 2, pp. 157-159.

[73] EPPING, G.M. (1982), "Important factors in plant location in 1980", *Growth and Change*, pp. 47-51.

[74] ERLENKOTTER, D. (1975), "Capacity planning for large multi-location system: Approximate and incomplete dynamic programming approaches", *Management Science*, vol. 22, no. 3, pp. 274-285.

[75] FAWCETT, P., MCLEISH, R. and OGDEN, I. (1992), Logistics Management, Financial Times and Pitman Publishing, Singapore.

[76] FERDOWS, K. (1989), "Mapping international factory networks", *Managing International Manufacturing*, Holland, pp. 3-21.

[77] FINNIE, J. (1988), "The role of financial appraisal in decisions to acquire advance manufacturing technology", *Accounting and Business Research*, vol. 18, no. 70, pp. 133 --139.

[78] FLAHERTY, M. (1996), Global Operations Management, McGraw-Hill, New York.

[79] FRANCIS, R. L. (1967), "On some problems of rectangular warehouse design and layout", *Journal of Industrial Engineering*, Vol. 18, pp. 595-604.

[80] FRAZER, J. (1968), Applied Linear Programming, Prentice Hall Publications, Englewood Cliffs, NJ.

[81] FRAZELLE, E. H. (1996), World-Class Warehousing, Atlanta: Logistics Resources International Inc.

[82] FREESE, T. L., (1997), Site Selection: How to Choose The Best Location for A New Plant or DC, Freese and Associates, Chagrin Falls, OH.

[83] FUENTE, D. and LOZANO, J. (1997), "Determining warehouse number and location in by cluster analysis", *International Journal of physical Distribution and Logistics Management*, Vol. 28, No.1, pp. 68-79.

[84] GARVIN, W. (1980), Introduction to Linear Programming, Prentice Hall Publications, NY.

[85] GASS, S. (1986) "A process for determining priorities and weights for large-scale linear goal programmes", *Journal of Operational Research Society*, vol. 37, no. 8, pp. 779-785.

[86] GATTORNA, J. *et al.*, (1988), "Effective logistics management", *International Journal Physical Distribution Materials Management*, vol. 18, no. 2/3, pp. 1-92.

[87] GEMMILL, D. D. and TSAI, Y. W. (1997), "Using a simulated annealing algorithm to schedule activities of resource-constrained projects", *Project Management Journal*, pp. 8-20.

[88] GEOFFRION A. M. and MCBRIDE, R. (1978), "Lagrangian relaxation applied to capacitated facility location problem", *AIIE Transaction*, vol 1, pp. 40–7.

[89] GHIANI, G., GUERRIEROB F. and MUSMANNO R. (2002), "The capacitated plant location problem with multiple facilities in the same site", *Computers and Operations Research*, vol 29, pp 1903–1912.

[90] GHOSH, A. and HARCHE, F. (1993), "Location-allocation models in the private sector: progress, problems, and prospects", *Location Science*, vol. 1, pp. 81-106.

[91] GHOSH, B. and WABALICKIS, R. (1991), "A comparative analysis for the justification of future manufacturing systems", *International Journal of Operations and Production Management*, vol. 11, no. 9, pp. 4-23.

[92] GIFFI, C., ROTH, A., and SEAL, G. (1990), Competing in World Class Manufacturing: America's 21st Century Challenge, Irwin, Homewood.

[93] GILGEOUS, V. and GILGEOUS, M. (1999), "A framework for manufacturing excellence", *Integrated Manufacturing Systems*, vol. 10, no. 1, pp. 33–44.

[94] GOLDENGORIN, B., GHOSH, D. and SIERKSMA, G., (2004), "Branch and peg algorithms for the simple plant location problem", *Computers and Operations Research*, vol. 31, pp 241–255.

[95] GREENE, A. (1991), "Plant-wide systems: a world class perspective", *Production Inventory Management*, vol. 11, no. 7, pp. 14-15.

[96] GUINARD, M. and KIM, S. (1987), "A strong Lagrangian relaxation for capacitated plant location problems", *Math Program*, vol. 39, pp. 215–28.

[97] GUNN, T. (1987), "Manufacturing for competitive advantage: becoming a World-class manufacturer", Ballinger Publishing: Cambridge, Massachusetts.

[98] HACH, J. J. (1995), "Less warehousing, better distribution", *Transportation and Distribution*, vol. 36, no. 3, 1995.

[99] HAFEEZ, K., ZHANG, Y. and MALAK, N. (2002), "Determining key capabilities of a firm using analytical hierarchy process", *International Journal of Production Economics*, vol. 76, no. 1, pp. 39-51.

[100] HANSEN, P.H., HEGEDAHL, B. and OBEL, B. (1994), "A heuristic solution to the warehouse location-routing", *European Journal of Operational Research*, July 6, Vol. 76, No. 1, pp. 111.

[101] KHAN, Z., PRASAD, B. and SINGH, T. (1996), "Machining condition optimization by genetic algorithms and simulated annealing", *Computers and Operations Research*, pp. 647-657.

[102] KIM, J. U. and KIM, Y. D. (1996), "Simulated annealing and genetic algorithms for scheduling products with multi-level product structure", *Computers and Operations Research*, pp. 857-868.

[103] KUIK, R. and SALOMON, M. (1990), "Multi-level lot sizing problems: evaluation of a simulated annealing heuristics", *European Journal of Operational Research*, vol. 45, pp. 25-37.

[104] KUIK, R., SALOMON, M., WASSENHOVE, L. N. and MAES, J. (1993), "Linear programming, simulated annealing and tabu search heuristics for lot sizing in bottleneck assembly systems", *IIE Transactions*, vol. 25, pp. 62-72.

[105] HALEY, B.K. (1962), "The siting of depots", *International Journal of Production Research*, vol. 7, pp. 41-45.

[106] HANDLER, G. and MIRCHANDANI, P. (1979), Location on Networks: Theory and Algorithms, MIT Press, Cambridge, MA.

[107] HARRISON, A. (1988), "Manufacturing strategy and the concept of world class manufacturing", *International Journal of Operations and Production Management*, vol.18, no.4, pp. 397-408.

[108] HARRISON, H. (1979), "A planning system for facilities and resources in distribution networks", *Interfaces*, vol. 9, no. 2, pp. 6-22.

[109] HAUG, P. (1985), "A multiple-period, mixed integer programming model for multinational facility location", *Journal of Management*, vol. 11, no. 3, pp. 83-96.

[110] HAX, A. and MAJLUF, S. (1983), "The industry attractiveness-business strength matrix in strategic planning", *Interfaces*, vol. 13, pp. 54-71.

[111] HAYTER, R. (1997), The Dynamics of Industrial Location: The Factory, the Firm and the Production Systems, John Wiley, Chichester.

[112] HODDER, J. E. and DANCER, M. C. (1986), "A multifactor model for international plant location and financing under uncertainty", *Computers and Operations Research*, vol. 13, no 5, pp. 601-609.

[113] HOFFMAN, J. and SCHNIEDERJANS, M. (1994) "A two-stage model for structuring global facility site selection decisions", *International Journal of Operations and Production Management*, vol. 14, no. 4, pp. 79-96.

[114] HOFFMAN, J. J. and SCHNIEDERJANS, M. J. (1996), "A two-stage model for structuring global facility site selection decisions: the case of the brewing industry", *Facilities*, vol. 14, no. 12/13, pp. 23–34.

[115] IOANNOU, G. and SULLIVAN, W. (1999), "Use of activity-based costing and economic value analysis for the justification of capital investments in automated material handling systems", *International Journal of Production Research*, vol. 37, no. 9.

[116] JACOBSEN S. K. (1983), "Heuristics for the capacitated plant location model", *European Journal Operation Research*, vol. 12, pp. 253–61.

[117] JACOB, V., NATESAN, T., and UTHAIRAJ, V. (2002), "Analysis of hybrid heuristic model algorithms for solving linear programming problems", *Operation Research Society of India*, Vol. 39, No. 3-4, pp. 21-27.

[118] JAPAN MANAGEMENT ASSOCIATION (ed.) (1986), Kanban: Just-In-Time at TOYOTA – Management begins at workplace, Productivity Press, Cambridge, Massachusetts.

[119] JAMES, I. and CAVALIER, T. (1994), Linear programming, Prentice Hall Publications, Englewood Cliffs, NJ.

[120] JOHNSON, J. C., WOOD, D. F., WARDLOW, D. L. and MURPHY, P. R (1999), Contemporary Logistics, Prentice-Hall Inc, New Jersey.

[121] JUCKER, J. and CARLSON, R. (1976) "The simple plant-location under uncertainty, *Operations Research*, vol. 24, no. 6, pp. 1045-1055.

[122] JUNGTHIRAPANICH, C. (1992), An Intelligent Decision Support System for Facility Location, Unpublished Dissertation, Department of Engineering Management, University of Missouri-Rolla.

[123] JUNGTHIRAPANICH, C. and BENJAMIN, C. (1995), "A knowledge-based decision support system for locating a manufacturing facility", *IIE Transactions*, vol. 27, pp. 789-99.

[124] KAKATI, M. and DHAR, U. (1991), "Investment justification in flexible manufacturing systems", *Engineering Costs and Production Economics*, vol. 21, no. 3, pp. 203-209.

[125] KANTER, R. (1995), World Class: Thriving Locally in the Global Economy (New York: Simon & Schuster).

[126] KAPLAN, R. (1983), "Measuring manufacturing performance: a new challenge for managerial accounting research", *The Accounting Review*, vol. 58, no. 4, pp. 686-703.

[127] KAPLAN, R. (1984), "Yesterday's accounting undermines production", *Harvard Business Review*, July-August, pp. 95-101.

[128] KENNINGTON, J. and UNGER, E. (1976) "A new branch and bound algorithm for the fixed-charge transportation problem", *Management Science*, vol. 22, no.10, pp. 1116-1126.

[129] KHUMAWALA B. M. (1974), "An efficient heuristic procedure for the capacitated warehouse location problem", *Naval Research Logistics Quarterly*, vol. 21, pp. 609–23.

[130] KIM, G., PARK, C., and YOON, K. (1997), "Identifying investment opportunities for advanced manufacturing systems with comparative-integrated performance measurement", *International Journal of Production Economics*, vol. 50, no. 1, pp. 23-33.

[131] KIM, P. O., LEE, K. J. and LEE, B. W. (1999), "Selection of an optimal nuclear fuel cycle scenario by goal programming and the analytical hierarchy process'", *Annals of Nuclear Energy*, vol. 26, pp. 449-60.

[132] KINNI, T. (1996), America's best: Industry Week's Guide to World-Class Manufacturing Plants, John Wiley, New York.

[133] KIRKPATRICK, S. C. D. GELLAT, J. R., and VECCHI, M. P. (1983), "Optimization by simulated annealing", *Science*, vol. 220, pp. 671-680.

[134] KLOSE, A. (1999), "LP-based heuristic for two-stage capacitated facility location problem", *Journal of the Operational Research Society*, vol. 50, no.2, pp. 157–166.

[135] KOCAOGLU, D. (1983), "A participative approach to program evaluation", *IEEE Engineering Management Review*, Vol. 8, pp.112-118.

[136] KODALI, R. and CHANDRA, S. (2001), "Analytical hierarchy process for justification of total productive maintenance", Production Planning and Control, vol. 12, no. 7, pp. 695-705.

[137] KOGUT, B. (1984), "Normative observations on the international value-added chain and strategic groups", *Journal of International Business Studies*, pp. 151-67.

[138] KORHONEN P. and WALLENIUS, J. (1990), "Using qualitative data in multiple objective programming", *European Journal of Operational Research*, vol. 48, pp. 81-87.

[139] KORPELA, J. and LEHMUSVAARA, A. (1999), "A customer oriented approach to warehouse network evaluation and design", *International Journal of Production Economics*, vol. 59, pp. 135-146.

[140] KORPELA, J. and TUOMINEN, M. (1995), "Decision support for defining the optimal logistical structure for a company by integrating linear optimisation and the analytic hierarchy process", *Revue des Systems de decision*, vol. 4, no.1, pp. 23-41.

[141] KORPELA, J., LEHMUSVAARA, A. and TUOMINEN, M. (1998), "Customer service based design of the supply chain", *Tenth International Working Seminar on Production Economics*, vol. 2, pp. 161-174.

[142] KORPELA, J., LEHMUSVAARA, A. and TUOMINEN, M. (1999), "An integrated approach for truck carrier selection", *International Journal of Logistics: Research and Applications*, vol. 2, pp. 1, pp. 5-20.

[143] KOULAMAN, C., ANTONY, S. R. and JEAN, R. (1994), "A survey of simulated annealing applications to operations research problems", *Omega*, vol. 22, pp. 41-56.

[144] KRAR, S. and GILL, A. (2002), "Justify your ROI", www.advanced manufacturing.com /January 02/exploringamt.htm.

[145] KUEHN, A. and HAMBURGER, M. (1963), "A heuristic program for locating warehouses", *Management Science*, vol. 9, no. 4, pp. 643-666.

[146] KUO, R. J., CHI, S. C. and KAO, S. S. (2002), "A decision support system for selecting convenience store location through integration of fuzzy AHP and artificial neural network", *Computers in Industry*, (in press).

[147] KUO, R. J., CHI, S.C. and KAO, S. S. (1999), "A decision support system for locating convenience store through fuzzy AHP", *Computers and Industrial Engineering*, vol. 37, pp. 323–326.

[148] KYPARISIS, G. J. *et al.*, (1996) "Project selection with discounted returns and multiple constraints", *European Journal of Operation Research*, vol. 94, no.1.

[149] LABIB, A. (1998), "World-class maintenance using a computerised maintenance management system", *Journal of Quality in Maintenance Engineering*, vol. 4, no. 1, pp 66-75.

[150] LAMBERT, D. M, STOCK, J. R. and ELLRAM, L. M. (1998), Fundamentals of Logistics Management, United States of America: Irwin McGraw-Hill.

[151] LEE, S. and FRANZ, L. (1979), "Opitimising the location-allocation problem with multiple objectives", *International of Physical Distribution and Materials Management*, vol. 9, no. 6, pp. 245-55.

[152] LEE, S., GREEN, G. and KIM, C. (1981), "A multiple criteria model for the location-allocation problem", *Computers and Operations Research*, vol. 8, no. 1, pp. 1-8.

[153] LEHMUSVAARA, A., KORPELA, J. and TUOMINEN, M. (1997), "Connecting customers preferences and importance and logistics capabilities in distribution network design", *Proceedings of the Fourth International*

Conference of the European Operations Management Association, Barcelona, pp. 3-8.

[154] LEUNG, J. M. and MAGNANTI T. L. (1989), "Valid inequalities and facets of the capacitated plan location problem", *Math Program*, vol. 44, pp 271–91.

[155] LEVITT, T. (1983), "The globalization of markets", *Harvard Business Review*, vol. 61, no. 3, pp. 93-102.

[156] LIBERATORE, M. J. and TITUS, G. J. (1983) "The practice of management science in R&D project management", *Management Science*, vol. 29, no.8, pp. 962-974.

[157] MACCARTHY, B. and ATTIRAWONG, W. (2001), "Critical factors in International decisions: A Delphi Study", *Proceedings of Twelfth Annual Conference of the Production and Operations Management Society*, March 30-April 2, Orlando Fl.

[158] MACCRIMMON, K. (1968), "Decision making among multiple-attribute alternatives", *The Rand Corp., Rep. RM-4823-ARPA*, December.

[159] MAHADEVAN, B. (1998), "Principles of world class manufacturing", *The Management Accountant*, pp. 645-649.

[160] MAIRS, T., WAKEFIELD, G., JONNSON, E. and SPIELBERG, K. (1978), "On a production allocation and distribution problem", *Management Science*, vol. 24, pp. 261-273.

[161] MARAZZI, C. (1985), "A value analysis method for the evaluation of telecommunication systems bid proposals", *IEEE Transactions on Engineering Management*, vol. EM-32, no. 2, pp. 55-62.

[162] MASKELL, B, (1994), Software and Agile Manufacturer, Productivity Press, Portland, Oregon.

[163] MASKELL, B. (1991), Performance Measurement for World-class Manufacturing, Productivity Press, Portland, Oregon.

[164] MCDONALD, A.L. (1986), "Of floating factories and mating dinosaurs", *Harvard Business Review*, vol. 64, no. 6, pp. 82-6.

[165] MELKOTE, S. and DASKIN, M. S. (2001), "Capacitated facility location/network design problems", *European Journal of Operational Research*, vol. 129, no. 3, pp. 481–495.

[166] MEREDITH, J. R. and SURESH, N. C. (1986), "Justification techniques for advanced manufacturing technologies", *International Journal of Production Research*, vol. 24, no. 5, pp. 1043-1057.

[167] METROPOLIS, N., ROSENBLUTH, A., ROSENBLUTH, M., and TELLER, E. (1953), "Equations of state calculations by fast computing machines", *Journal of Chemical Physics*, vol. 21, pp. 1087-1092.

[168] MEYER, C. (1973), "A long-run selection and timing analysis system for facility location: implementation", *Management Science*, vol. 20, pp. 261-273.

[169] MICHAEL, G. J. and MILLEN, R. A. (1985), "Economic justification of modern computer-based factory automation equipment: a status report", *Annals of Operations Research*, vol. 3, no. 3, pp. 25-34.

[170] MILES, L. (1972), Techniques of value analysis and engineering, McGraw-Hill Book Company, New York.

[171] MOERMAN, P. A. (1988), "Economic evaluation of investments in new production technologies", *Engineering Costs and Production Economics*, vol. 13, pp. 241-262.

[172] MULCAHY, D. E. (1994), Warehouse distribution and operations handbook, McGraw-Hill Inc.

[173] MURTAGH, B. (1981), Advanced Linear Programming; Computation and Practice, McGraw-Hill Publications, NY.

[174] MURTY, K. (1976), Linear and combinatorial programming, Wiley Publications, NY.

[175] NAIK, B. and CHAKRAVARTY, A.K. (1994), "A strategy for locating a network of international manufacturing facilities", *Proceedings of the Symposium on Globalization of Technology, Manufacturing and Service Operations*, Tulane University, New Orleans, LA.

[176] NANDI, S. and BANWET, D. (2000), "Benchmarking for world class manufacturing-Concept, framework & applications", *Productivity*, vol. 41, no. 2, pp 189-200.

[177] NANTHAVANIJ, S. and YENRADEE, P. (1999), "Predicting the optimum number, location, and signal sound level of auditory warning devices for manufacturing facilities", *International Journal of Industrial Ergonomics*, vol. 24, no. 6, pp. 569–578.

[178] NOBUAKI, S., AKIRA, U., ATSUSHI, D., AKIRA, O., SEIJI, S. and SATOSHI, H., (1998), "Commercial facility location model using multiple regression analysis", *Computers Environment and Urban Systems*, vol. 22, no. 3, pp. 219–240.

[179] OLSON, D. L., MUNIRPALLAM, V. and MOTE, J. L. (1986), "A technique using analytical hierarchy process in multi-objective planning models", *Socio-Economical Planning Sciences*, vol. 20, no. 6, pp. 361-368.

[180] OWEN, S. H. and DASKIN, M. S. (1998), "Strategic facility location: a review", *European Journal of Operational Research*, Vol. 111, pp 423-447.

[181] PARADA, V., SEPULVEDA, M. and SOLAR, M. (1998), "Solution for the constrained guilotine cutting problem by simulated annealing", *Computers and Operations Research*, pp. 37-47.

[182] PARSAEI, H. R. and WILHELM, M. R. (1989), "A justification methodology for automated manufacturing technologies", *Journal of Computers and Industrial Engineering*, vol. 16, no. 3, pp. 341-346.

[183] PARSAEI, H. R., KORWOWSKI, W., and WILHELM, M. R. (1988), "A methodology for economic justification of flexible manufacturing systems", *Computers and Industrial Engineering*, vol. 15, no. 1- 4, pp. 117-122.

[184] PARTOVI, F. Y. (1994), "Determining what to benchmark: an analytic hierarchy process approach", *International Journal of Operations and Production Management*, vol. 14, no. 6, pp. 25-29.

[185] PATEL, N. (1979), "Locating rural social service centres in India", *Management Science*, vol. 25, pp. 22-30.

[186] PAUL, L. (1964), Linear programming; an introductory analysis, Tata-McGraw Hill Publications, Bombay.

[187] PORTER, M. E. (1985), Competitive Advantage, Free Press, New York.

[188] PRIMROSE, P. (1999), Investment in Manufacturing Technology, Chapman and Hall, London.

[189] PUTTERILL, M., MAGUIRE, W., and SOHAL, A. (1996), "Advance manufacturing technology investment: criteria for organizational choice and appraisal", *Integrated Manufacturing Systems*, vol. 7, no. 5, pp. 12-24.

[190] RAAFAT, F. (2002), "A comprehensive bibliography on justification of advanced manufacturing systems", *International Journal of Production Economics*, vol. 79, pp. 197-208.

[191] RADCLIFFE, L. L. and SCHNIEDERJANS, M. J. (2004), "Trust evaluation: an AHP and multi-objective programming approach", *Management Decision*, vol. 41, no.6, pp. 587-595.

[192] RAMASESH, R. and JAYAKUMAR, M. (1993), "Economic justification of advanced manufacturing technology", OMEGA, *International Journal of Management Science*, vol. 21, no. 3, pp. 289-306.

[193] RAO, K. and DESHMUKH, S. (1997), "A decision support system for selection and justification of advanced manufacturing technology", *Production Planning and Control*, vol. 8, no. 3, pp. 270-284.

[194] RARDIN, R. (1998), Optimization in Operations Research, Prentice Hall Publications, New Jersey.

[195] RAVINDRAN, A., PHILLIPS, D., and SOLBERG, J. (2000), Operations Research: Principle and Practice, John Wiley and Sons Publications, Singapore

[196] REMER, D. S. and MATTOS, F. B. (2003), "Cost and scale-up factors, international inflation indexes and location factors", *International Journal of Production Economics*, vol 84, pp. 1-16.

[197] REVELLE, C. S. and LAPORTE, G. (1996), "The plant location problem: new models and research Prospects", *Operations Research*, vol. 44, no. 6, pp. 864-74.

[198] REVELLE, C., BIGMAN, D., SCHILLING, D., COHON, J. and CHURCH, R. (1977), "Facility location: a review of context-free and EMS models", *Health Services Research*, pp.129-46.

[199] ROBINI, M. C., RASTELLO, T. and MAGNIN I. E., (1999), "Simulated annealing, acceleration techniques, and image restoration", *IEEE Transaction on Image Processing*, vol. 8, no. 10, pp.1374 –1387.

[200] ROGER, N. (1987), "Justification of FMS with the analytical hierarchy process", *Journal of Manufacturing*, vol. 7, no. 3, pp. 175-182.

[201] ROSENTHAL, R., WHITE, J. and YOUNG, D. (1978), "Stochastic dynamic location analysis", *Management Science*, vol. 24, no. 6, pp. 645-653.

[202] ROSS, G.T. and SOLAND, R.M. (1980), "A multi-criteria approach to the location of public facilities", *European Journal of Operational Research*, vol. 4, pp. 307-21.

[203] RUSSELL, R. and TAYLOR, B. III (1998), Operations Management: Focusing on Quality and Competitive, Prentice-Hall, NJ.

[204] SAHAY, B., SAXENA, K., and KUMAR, A. (2000), World-class Manufacturing: A Strategic Perspective, Macmillan India Limited.

[205] SÁNCHEZ-ANTE G., RAMOS, F. and FRAUSTO, J. (1999), "Locally-optimal path planning by using probabilistic roadmaps and simulated annealing", *Proceedings IASTED International Conference in Robotics and Application.*

[206] SARKER, R. and NEWTON, C. (2000), "Solving A Multiple Objective Linear Program Using Simulated Annealing", *The 5th Conference of Association of the Asian-Pacific Operations Research Societies*, Singapore.

[207] STRAYER, J. (1979), Linear Programming and its Applications, Narosa Publications, New Delhi.

[208] SATTY, T. L. (1980), The Analytic Hierarchy Process, McGraw-Hill, New York.

[209] SATTY, T. L. (2000), Fundamentals of Decision Making and Priority Theory, 2nd edition, RWS Publications, Pittsburgh.

[210] SCHMENNER, R. W. (1982), Making Business Location Decisions, Prentice-Hall.

[211] SCHMENNER, R. W. (1994), "Service firm location decisions: some Midwestern evidence" *International Journal of Service Industry Management*, vol. 5, no. 3, pp. 35-56.

[212] SCHNIEDERJANS, M. J. and GARVIN, T. (1997), "Using the analytical hierarchy process and multi-objective programming for the selection of cost drivers in activity-based costing", *European Journal of Operational Research*, vol. 100, pp. 72-80.

[213] SMALL, M. (1998), "Objective for adopting advanced manufacturing systems: promise and performance", *Industrial Management and Data Systems*, vol. 98, no.3-4, pp. 129-137.

[214] SON, Y. (1992), "A comprehensive bibliography on justification of advanced manufacturing technologies", *The Engineering Economist*, vol. 38, no. 1, pp. 59-71.

[215] SRIDHARAN, R. (1995), "The capacitated plant location problem", *European Journal of Operational Research*, vol. 87, pp 203-213.

[216] STOCK, J. R. and LAMBERT, D. M. (1987), "Strategic Logistics Management", Irwin, Homewood.

[217] SULE, D. (1994), Manufacturing Facilities: Location, Planning and Design, PWS Publishing Company, Boston, MA.

[218] SWEERSEY, A. and THAKUR, L. (1995), "An integer programming model for locating vehicle emissions testing stations", *Management Science*, March, Vol. 41, No.3

[219] SWEENY, D. and TATHAM, R. (1976), "An improved long-run model for multiple warehouse location", *Management Science*, vol. 22, pp. 748-758.

[220] THAYER, A. (1995), "Justifying technology's value challenges industry R&D managers", *Chemical and Engineering News*, vol. 73, no.6, pp. 10-14.

[221] THIZY, J. M., VAN WASSENHOVE, L. and KHUMAWALA, B.M. (1980), "Comparison of exact and approximate methods of solving the un-capacitated plant location problem'', *Journal of Operations Management*, vol. 6, no. 1, pp. 23-34.

[222] TOMPKINS, J. A., WHITE, J. A., BOZER, Y. A., FRAZELLE, E. H., TANCHOCO, J. and TREVINO, J. (1996), Facilities Planning, John Wiley, New York.

[223] TONG, H. M. (1979), Plant Location Decision of Foreign Manufacturing Investors, UMI Research Press, Michigan.

[224] TONG, H.M. and WALTER, C. K. (1980), "An empirical study of plant location decisions of foreign manufacturing investors in the United States", *Columbia Journal of World Business*, pp. 66-73.

[225] TOONE, R. (1999), "World class manufacturing: Myth or Reality", *Control*, pp 24-27.

[226] TOREGAS, C., SWAIN, R., REVELLE, C. and BERGMAN, L. (1971), "The location of emergency service facilities", *Operations Research*, vol. 19, pp. 1363-1373.

[227] TRIGGS, D. (1993), "Justifying investment in technology", *Logistics Information Management*, vol. 6, no.5, pp.20-26.

[228] TROXLER, J. and BLANK, L. (1990), "A comprehensive methodology for manufacturing system evaluation and comparison", *Journal of Manufacturing Sources*, vol. 9, no.3, pp. 175-183.

[229] TZENG, G. H. and CHEN, Y. W. (1999), "Optimal location of airport .re stations: a fuzzy multi-objective programming and revised genetic algorithm approach", *Transportation Planning and Technology*, vol. 23, no. 1, pp. 37–55.

[230] VAJDA, S. (1974), Theory of linear and non linear programming, Longman Publications, London.

[231] Vereecke, A. and Dierdonck, V. R. (2002), "The strategic role of the plant: testing Ferdows's model", *International Journal of Operations and Production Management*, vol. 22, no. 5, pp. 492-514.

[232] WALKER, W. (1976), "A heuristic adjacent extreme point algorithm for the fixed-charge problem", *Management Science*, vol. 22, no. 5, pp. 587-596.

[233] WALLACE, W. and THUESEN, G. (1987), "Annotated bibliography of investing in flexible automation, The Engineering Economist, vol. 32, no. 3, pp. 247-257.

[234] WANG, J. and MALAKOOTI, B. (1992), "A feed forward neural network for multiple criteria decision-making", *Computers in Operations Research*, vol. 19, no. 2, pp. 151–167.

[235] WATTS, H. (1987), Industrial Geography, Wiley, New York.

[236] WANG, T., SONG, J. and CHEN, L. (2001), "The economic justification of machine change over time reduction in a manufacturing cell", International *Journal of Computer Integrated Manufacturing*, vol. 14, no. 4, pp. 409-420.

[237] WEBER, A. "Alfred Weber's Theory of the Location of Industries", University of Chicago, 1929.

[238] WESOLOWSKY, G. (1977), "Probabilistic weights in the one-dimensional facility location problem", *Management Science*, vol. 24, no. 2, pp. 224-229.

[239] WESOLOWSKY, G. and TRUSCOTT, W. (1975), "The multi-period location allocation problem with relocation of facilities", *Management Science*, vol. 22, no. 1, pp. 57-65.

[240] WILNER, N., KOCH, B., and KLAMMER, T. (1992), "Justification of high technology capital investment -an empirical study", *Engineering Economist*, vol. 37, no. 4, pp. 341-353.

[241] WOLSEY, L. A. (1998), Integer programming, New York: Wiley.

[242] YAMASHINA, H. (2000), "Challenge to world-class manufacturing", *International Journal of Quality and Reliability Management*, vol. 17, no. 2, pp 132-143.

[243] YANG, J. and LEE, H. (1997), "An AHP decision model for facility location selection", *Facilities*, vol. 15, no. 9/10, pp 241-254.

[244] YANG, S., MACHADO, J. M., NI, G., HO, S. L. and ZHOU, P. (2000), "A self-learning simulated annealing algorithm for global optimizations of electromagnetic devices", *IEEE Transaction on Magnetics*, vol. 36, no. 4, part one, pp. 1004-1008.

[245] YIP, G. (1993), "Locating global activities", *Proceedings of the Symposium on Globalization of Operations Management, Georgetown University*, Washington, DC.

[246] YOON, K. and WANG C. (1985), "Manufacturing plant location analysis by multiple attribute decision-making: part-1: single plant strategy", *International Journal of Production Research*, vol. 23, no. 2, pp. 345-359.

[247] YOON, K. P. and HWANG, C. L. (1995), Multiple Attribute Decision Making: An Introduction, Quantitative application in Social Sciences, Thousand Oaks, CA: Sage.

[248] YURIMOTO, S. and MASUI, T. (1995), "Design of a decision support system for overseas plant location in the EC", *International Journal of Production Economics*, vol. 41, pp 411-418.

[249] ZAHRAN, I. M., ELMAGHRABY, A. S., and SHALABI, M. A. (1992), "Justification of cellular manufacturing systems", *Economics of advanced manufacturing systems*, edited by Parsaei, H. R. and Mittal, A., Chapman and Hall, London.

[250] ZELENY, M. (1974), Linear Multi-objective Programming, S.V. Publications, Berlin.

[251] ZELENY, M. (1998), "Multiple Criteria Decision Making: Eight Concepts of optimality", *Human Systems Management*, vol. 17, pp. 97-107.

Chapter 4

Design of Transportation Driver in Supply Chain Management

4.1 Introduction

The most fundamental characteristic of economic society is trade. Transportation is inseparable from trade. Transportation, more than anything else, determines the "extent of the market". Economic progress would be virtually impossible without the ability to carry goods from place to place efficiently and cheaply. Distance has ceased to be an obstacle to trade or travel. Needless to say, the improvement in transportation, which has made possible the modern system of commerce, has brought about a vast improvement in the standard of living of all people. Logistics and transportation managers are facing a very different environment today from a few years ago. There is continued economic deregulation, increased safety and social regulation, constant escalation of customer expectations, increased globalization, constant improvements in technologies, and labour and equipment shortages. All of this leads to a continual change in the transportation service industry and presents today's managers with an array of challenges and opportunities that contrast dramatically with those of a decade ago. Many managers have failed to adapt fully to the changing environment, resulting in performance shortcomings and lost opportunities. One of the most prominent among the list of lost opportunities is the prospect of further leveraging the transportation function as a critical strategic element in the supply chain. According to Moultrie (1998), shippers time and again take transportation decisions using logic, thereby making uninformed decisions. In order to meet growing expectations, there has been a shift from the basic task of transportation and operationally obtaining low cost or high service criteria to providing a strategic edge by concurrently obtaining elevated service requirements and lower cost. Today's managers require a broad view of the role and responsibilities of an integrated supply chain. Abdinour (1999) is of opinion that the improvement of the efficiency of the transport function directly related is to the customer network in the supply chain. The transport function is seen as an internal service function of any operation of a company and is directly linked to customer satisfaction. Smooth and flawless distribution can be an almost unattainable goal at times, and companies are permanently experimenting with their distribution channels to make them more flexible and reactive. The reduction or shortening of delivery times is not a new concept. Numerous businesses are aware that logistics costs can be between 10% and 35% of a company's gross revenues, logistics is the single highest operating cost. Milligan (2000) states that "with most supply chain activities, about 80% of the cost is going to be transportation, while about 20% will cover the cost of warehousing and cross-dock activities". Milligan stipulates furthermore that transport tends to be monotonous and that the activity is not the main budget item in most companies. Managers view the transportation activity as something that is not of the greatest importance and that nobody is concerned about it until the costs start escalating (Milligan, 1999). This should not be the case if one considers the cost of transport in the United States for example. The cost of transport in the United States, in 1990 was $352 billion (Lambert *et al.*, 1993). In 1999 the cost of transport was recorded to be $548 billion (Lambert *et al.*, 2001). Transport cost as a percentage of total logistics cost increased from 58% in 1990 to 59% in 1999. According to Factor (2001), the controlling and managing of transportation costs could result in a 5% to 15% decline in overall transportation costs. The problem lies in the fact that transportation is often just an afterthought and rarely well planned. In most companies, management also see transportation as a necessary evil in order to get the product to the customer and not as part of the company's core competencies (Milligan, 2000). Milligan (2000) stipulates "one of the main causes of excessive transportation costs in the supply chain is the lack of involvement from the purchasing managers in transportation planning". Purchasing managers should in general be made more conscious of the impact that transportation cost can have on the purchase price of goods. There needs to be an understanding that it might be more feasible to purchase a product or goods from an alternative location than was previously thought. Purchasing managers should however understand that those types of decisions cannot easily be made without the involvement of transportation managers to ensure that the most cost-effective decision is made and total supply chain costs kept to a minimum (Milligan, 2000). A typical scenario where excess transportation costs are incurred would be where somebody from production or sales would issue an emergency order and say that they need it the next day, totally unaware of the freight cost (Milligan, 1999). People will move a product at all costs to get it to the right place at the right time to ensure optimal customer service and still negotiate insistently on the actual cost of the product. The main problem is not what it will take to service the customer, but that these decisions are made without people understanding what the impact will be on profitability (Drickhammer, 2002). Some managers believe that freight costs are always taken care of when goods are ordered and that the company is not paying transportation costs for any incoming goods, as it has already been included in the purchase price. The simple truth is that those who believe that there are no costs involved are merely allowing someone else to decide how much the company will spend (Milligan, 1999). Braddy

(2002) is of the opinion that significant supply chain cost reductions from a transportation perspective can be obtained, but that one needs to look further than network optimization and rate reductions with carriers. Opportunities in reducing transportation costs on the provider's side still exist, although it is limited. There are however unexplored avenues of savings opportunities in managing inbound inventory, reducing static inventory and increasing supply chain velocity. The challenges lie however, in collaboration across the critical activities in the supply chain where information should be shared. The traditional methods used by shippers to counter inevitable increases in transportation costs are competitive bidding, optimization of networks, redesign of networks and, lastly, a repetition of the previous steps (Braddy, 2002). These methods involve network, lane and node decision-making, and will be discussed later in the chapter. Braddy (2002) is of the opinion that great savings can be obtained by looking at internal planning processes and collaboration. One of the main reasons for the failure of shippers to achieve strategic savings is locked in the fact that they maintain safety stock as a hedge against inconsistency in the supply chain. It is believed that safety stock can account for between 5% and 25% of the total inventory investment. Critical logistics planning on the inbound and outbound transportation, inventory management, production planning, warehousing, distribution and purchasing are needed to reduce static inventory. All these functions have a significant impact on inventory but the integration remains a complex task. Integration can however be achieved through enhanced information management and collaboration across planning functions. It is however also essential that there be visibility, whether it is the plant manager that can see inventory on the floor, in the yard or in transit. This will allow the manager to make informed decisions regarding transportation and safety stock to be held (Braddy, 2002). According to Gattorna

(1997), customers and consumers have become more conscious of their power in competitive markets. The suppliers' retort was bespoke services to meet specific customer expectations. This on the other hand requires a more integrated and coordinated approach to react to the ever-changing environment and to be able to react quicker. Suppliers are now working together to obtain lower total supply chain costs and to offer value-added services in an attempt to gain competitive market advantage. According to Gattorna (1997), this has led to the fact that the supply chain has become more intricate and, in particular, the transport activity. Gattorna (1997) stipulates that suppliers in the retail grocery industry in the United States can serve as an example. The suppliers have undertaken a number of initiatives designed to reduce supply chain inventories. The direct results of this were increased transport costs. The initiatives included:

Continuous replenishment: Smaller deliveries were made more often to replenish the units that were sold in order to prevent inventory build-up (Gattorna, 1997).

Cross-docking: Products were sourced from numerous suppliers in small quantities and then consolidated in a cross-docking distribution centre for distribution to the final destination. The cost of small shipments is very high, however, and increased the total transportation costs (Gattorna, 1997).

Selective sourcing: Distribution centres were rationalized in an attempt to minimize the total inventory holding. Stock was selectively being positioned at different points in the channel based on sales volumes. This led to an increase in transportation costs (Schary *et. al.*, 1995).

Postponement: The differentiation of goods was delayed until the latest point in the marketing flow to minimize both risk and inventory. The problem was that more rapid response meant increased transportation costs (Gattorna, 1997).

4.2 Development of decision support system framework for design of transportation driver

A decision support system framework is developed for design of transportation driver in SCM, which consists of four phases and it is shown in figure 4.1. Each phase is discussed below.

Selection of mode (Phase I): The objective of the first phase is to select the transportation mode for the organization. The mode of transportation is the manner in which a product is moved from one location in supply chain network to other. Phase I starts with clear definition of supply chain strategy (i.e. capabilities the supply chain network must have to support a firm's competitive strategy) of the organization. Then qualitative and quantitative factors are identified and compared with respect to supply chain strategy for feasible transportation modes. The feasible transportation modes should be ranked using ELECTREE III (Elimination and Choice Translating Reality; English translation from the French original).

Route and network (Phase II): Another major decision, managers must make is the route and network along which products are shipped. A route is the path along which a product is shipped and a network is the collection of locations and routes along which a product can be shipped. Therefore, a company needs to decide whether to ship the products directly to the customers or to use a series of distribution layers. Managers must decide on the customers to be visited by a particular vehicle and the sequence in which they will be visited. The success of this operations turns on its ability to decrease transportation and delivery cost while providing the desired level of responsiveness to the customer. Saving matrix method is used to solve these problems as it is simple to implement and used to assign customers to vehicles even when the delivery time windows or other constraints exists. This is the objective of second phase.

Transportation logistics: outsourcing or insourcing (Phase III): During the third phase of the process, the transportation logistics are analyzed to know whether to go for in-sourcing or outsourcing. The analysis is to be carried out to see its effect on core business, supply chain cost, improved customer service and capital utilisation.

Selection of carrier (Phase IV): During the fourth phase of the process, the selection of carrier is carried out using PROMEETHEE II (Preference ranking organization method). To use PROMEETHEE II, the qualitative factors, quantitative factors, threshold functions and different thresholds are identified.

Development of decision support system framework for design of transportation driver is discussed in the following section.

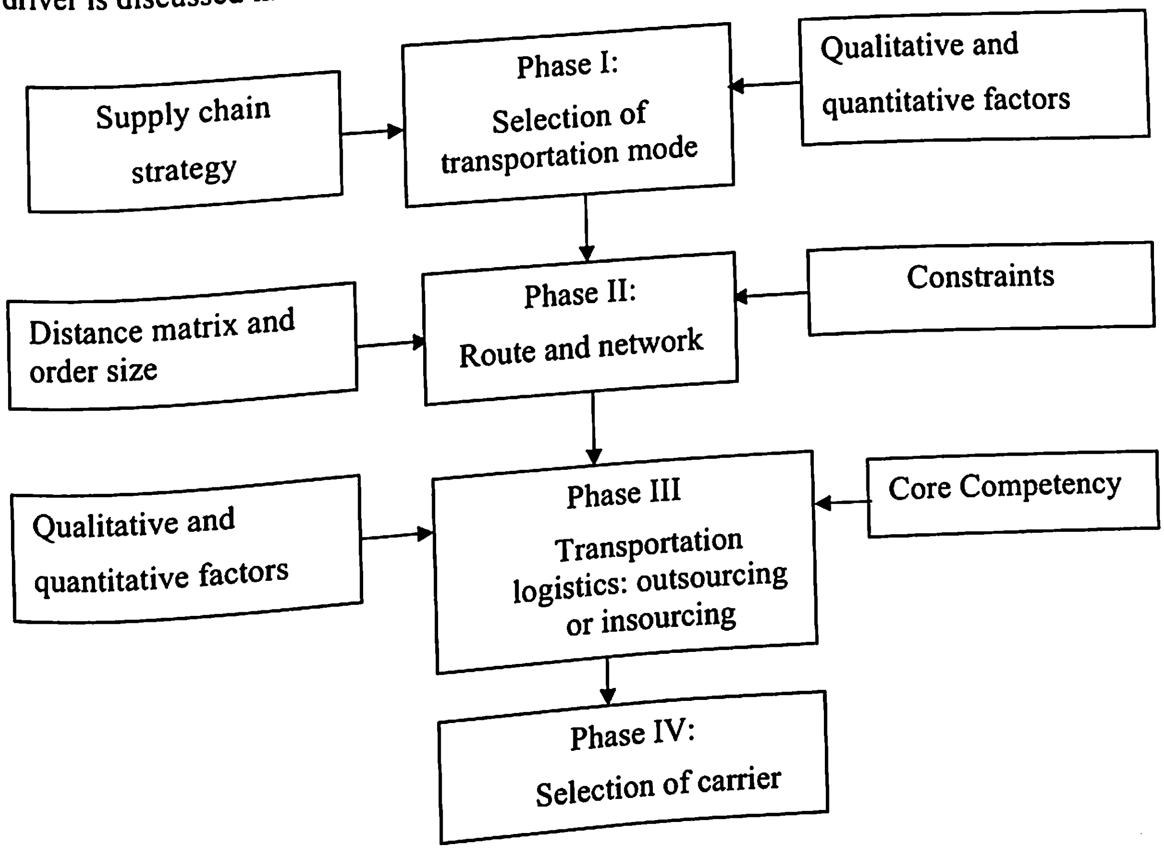


Figure 4.1: A decision support system framework for design of transportation driver

4.2.1 Development of ELECTREE III for selection of transportation mode

The choice of the transport mode or inter-mode is the fundamental part of supply chain management, which should be analyzed carefully because of its strategic impact upon a company's operational efficiency. Failure to identify the most appropriate transport mode may incur higher costs than are necessary and may provide a lower customer service level than is potentially possible. The basic modes of transportation available to logistics manager are rail, motor, water, pipeline and air. But environmental awareness has led to development of another means of transport, the ropeways. Each mode has different economic and technical structures and each can provide different qualities of link services (Coyle, 2003). In addition to these modes, inter-modal combinations are available: rail-motor (piggyback), motor-water (fishy back), motor-air (air-truck) and rail-water (trainship). It came to existence in 1960s. The primary motive behind developing the inter-modal transportation was to cut down the cost of cargo handling, reduce shipping time at the port and achieve economies of scale (Kapoor and Kansal, 2003). The decision upon the transport modal or inter-modal choice is extremely complex, as both the qualitative and quantitative factors have to be considered. Based on preliminary analysis, the logistics executives identified possible modes i.e. Road transport, Rail transport, Inland transport and Inter-modal transport. Among these modes, the best mode has to be selected. A thorough analysis of the problem is required along with the identification of the important attributes involved. The selection of the attributes is determined through literature survey and discussions held with experts. The attributes for selection of mode are as follows:

- Transportation cost [TCT]
- Inventory [INV]
- Reliability [REL]
- Flexibility [FLX]
- Transportation time [TPT]
- Safety [STY]
- Capacity [CAP]
- Density of network [DON]
- Impact [IMP]
- Image [IMA]
- Regulation and legislation [RAL]
- Strategic [STR]
- Product related factors [PRF]

Alternatives

The company X is involved in an automotive production and case situation is discussed in table 4.1. The feasible transportation mode is: road transport, rail transport and inter-modal transport. These alternatives are evaluated and compared in the light of above discussed set of attributes.

- Road transport [ROT]
- Rail transport [RAT]
- Inter-modal transport [IMT]

The ELECTRE (for Elimination and Choice Translating Reality; English translation from the French original) method was first introduced in (Benayoun *et al.*, 1966). The extensive methodological development and refinements that followed (Roy, 1968, 1971, 1990, 1991 and 1996) have made ELECTRE a widely used decision in many applied management areas (Roy and Hugonnard, 1982 and Massam and Askew, 1983). The different versions of ELECTRE have been developed (I, II, III, IV and TRI). All methods are based on the same fundamental concepts but differ operationally. Specifically, ELECTRE I is designed for selection problems, ELECTRE TRI for assignment problems and ELECTRE II, III and IV for ranking problems. ELECTRE II is an old version; ELECTRE III is used when it is possible and desirable to quantify the relative importance of criteria and ELECTRE IV when this quantification is not possible. The basic concept of the ELECTRE method is to deal with "outranking relations" by using pair wise comparisons among alternatives under each one of the criteria separately. The ELECTRE method begins with pair wise comparisons of alternatives under each criterion. Using physical or monetary values g_j (a) and g_j (b) of the alternatives '*a*' and '*b*' respectively, and introducing threshold levels for the difference $g_j(a) - g_j(b)$, the decision maker may declare that he/she is indifferent between the alternatives under consideration, that he/she has a weak or a strict preference for one of the two, or that he/she is unable to express any of these preference relations. Therefore, the set of binary relations of alternatives, the so-called outranking relations, may be complete or incomplete. Next, the decision maker is requested to assign weights to the criteria in order to express their relative importance. Through a series of consecutive assessments of the outranking relations of the alternatives, ELECTRE finds the so-called concordance index, defined as the amount of evidence to support the conclusion that alternative 'a' outranks, or dominates, alternative 'b', as well as the discordance, the counter-part of concordance index. The first step of the process is to establish the decision maker's sets of threshold levels. These threshold determined by using decision makers input, are the fundamental components for the subsequent outranking of alternatives. The threshold values will serve as indicators, generically the upper and lower acceptable limits, for criteria performance in the ensuing concordance/discordance analysis: specifying one alternative's dominance over another. ELECTRE uses four different threshold levels (Roy and Vincke, 1984 and Vincke, 1990).

- Strong preference threshold (p): It is the range within which a criterion's preferred performance lies.
- Weak preference threshold (q): It is an intermediate or buffer zone. A criterion's performance within this range is still accepted and aspired, however it represents decision maker's hesitation between (p) and (i).
- Indifference threshold (i): It represents the range that a criterion can move within before the variation significantly affects the desired state of criterion.
- Veto threshold (v): It signifies the absolutely highest or lowest value that a criterion can take on before the decision maker would find its performance unacceptable.

4.2.1.1 Algorithm

The steps to follow in ELECTRE III are:

Step 1 Define the problem and determine the objective.

Step 2 Identify the alternatives (a_i) available (The alternatives are: Location A, Location B, and Location C).

Step 3 Determine the attributes/criteria/performance indicators (b_j) that govern the problem.

Step 4 Classify the attributes/criteria/performance indicators into direct (performance grows while measure increases) and indirect categories (performance grows while measure decreases).

Step 5 Form the performance matrix, i.e., co-efficient g_{ij} related to the attribute/criterion/performance indicator b_j (j = 1, 2 ...n) and the alternative a_i (i=1, 2 ...m) (Steps 3, 4, and 5 are shown in Table 4.2).

Step 6 Quantify the qualitative attributes using the scale of 1 to 10, where 1 means very low, 3 means low, 5 means medium, 7 means high, and 9 means very high.

Step 7 Absolute weight-age W_j on a suitable scale (say 1 to 10) is assigned for each attribute/criterion/performance indicator reflecting the normative judgment of the decision maker.

Step 8 Form the threshold matrix using the strong preference threshold value (p_j), indifference threshold value (q_j) and veto threshold value (v_j) for each attributes/criteria/performance indicators (see table 4.2).

Step 9 Evaluate the concordance index for each criterion j for every pair of alternatives as indicated below:

- Direct category (when performance increases while measure increases)

$$c_j(a_1,a_2) = \begin{cases} 1 & \text{if } g_j(a_1)+q_j \geq g_j(a_2) \\ 0 & \text{if } g_j(a_1)+p_j \leq g_j(a_2) \\ \left[\dfrac{p_j - g_j(a_2)+g_j(a_1)}{p_j - q_j}\right] & \text{otherwise} \end{cases}$$

- Indirect category (when performance grows while measure decreases)

$$c_j\ (a_1, a_2) = \begin{cases} 1 & \text{if } g_j(a_1) - q_j \leq g_j(a_2) \\ 0 & \text{if } g_j(a_1) - p_j \geq g(a_2) \\ \left[\dfrac{p_j - g(a_1) + g_j(a_2)}{p_j - q_j}\right] & \text{otherwise} \end{cases}$$

Step 10 Compute the measure of concordance for every pair of alternatives taking into account the relative importance (w_j) of each criterion to construct the concordance matrix (see in table 4.3) as follows:

$$C\ (a_1, a_2) = \frac{\sum_{j=1}^{n} w_j\, c_j\,(a_1, a_2)}{\sum_{j=1}^{n} w_j}$$

Where n is number of criteria and w_j is relative importance of criteria j.

Step 11 Evaluate the discordance index for each criterion j for every pair of alternatives (see in table 4.4-4.16) as indicated below:

- For Direct category

$$d_j\ (a_1, a_2) = \begin{cases} 0 & g_j(a_1) + p_j \geq g_j(a_2) \\ 1 & g_j(a_1) + v_j \leq g_j(a_2) \\ \left[\dfrac{g_j(a_2) - g_j(a_1) - p_j}{v_j - p_j}\right] & \text{otherwise} \end{cases}$$

- Indirect category

$$d_j(a_1,a_2) = \begin{cases} 0 & g_j(a_1)-p_j \le g_j(a_2) \\ 1 & g_j(a_1)-v_j \ge g_j(a_2) \\ \left[\dfrac{g_j(a_1)-g_j(a_2)-p_j}{v_j-p_j}\right] & \text{otherwise} \end{cases}$$

Step 12 Evaluate the credibility degree/index for every pair of alternatives to construct the credibility matrix (see in table 4.17) as follows:

$$S(a_1,a_2) = \begin{cases} C(a_1,a_2) & dj(a_1,a_2) \le C(a_1,a_2) \quad \forall j = 1,\ldots,n \\ C(a_1,a_2) \prod\limits_{j\in J(a_1,a_2)} \dfrac{1-dj(a_1,a_2)}{1-C(a_1,a_2)} & \text{otherwise} \end{cases}$$

Step 13 Evaluate the ranking exploitation index T for every pair of alternatives to construct the ranking exploitation matrix (see table 4.18) as follows:

$$T(a_1,a_2) = \begin{cases} 1 & \text{if } S(a_1,a_2) > \lambda - s(\lambda) \\ 0 & \text{otherwise} \end{cases}$$

Where $\lambda = \max S(a_1,a_2)$ and $s(\lambda)$ is given by the user.

Step 14 Construct the pre-orders (Z_1) (see table 4.19) of the alternatives using the descending distillation process as indicated below: Evaluate the qualification of each alternative by row sum minus the column sum of the ranking exploitation matrix. The alternative(s) with highest quantification is (are) assigned to a rank and removed from the procedure, and the process is repeated with all remaining alternatives. When assignment is achieved for all alternatives, the process is complete.

Step 15 Construct the pre-orders (Z_2) (see table 4.19) of the alternatives using the ascending distillation process expect that the alternative(s) with smallest (rather than largest) qualification is declared the first distillate of the ascending chain.

Step 16 The results of Z_1 and Z_2 are combined to yield a final ranking consistent with both (see table 4.19).

Table 4.1: Case situation

Supply chain strategy	Somewhat responsive
Type of organization	Automotive production
Organizational culture	Moderate risk taking
Product strategy	Moderate profit margin and supplier risk

Table 4.2: Performance matrix

	WA	NA	ROT	RAT	IMT	q_j	p_j	v_j
[TCT]	0.1	Indirect	3000	2400	2600	100	300	700
[INV]	0.1	Indirect	500	1000	700	100	300	600
[REL]	0.075	Direct	10	6	8	1	2	4
[FLX]	0.05	Direct	10	6	7	1	2	5
[TPT]	0.05	Indirect	6	10	8	1	2	5
[STY]	0.1	Direct	10	6	9	1	2	5
[CAP]	0.05	Direct	7	10	9	1	3	5
[DON]	0.075	Direct	10	7	8	1	2	4
[IMP]	0.05	Direct	10	6	8	1	3	5
[IMA]	0.05	Direct	10	6	8	1	3	5
[RAL]	0.05	Indirect	6	10	8	1	2	5
[STR]	0.05	Direct	10	6	7	1	2	5
[PRF]	0.2	Direct	10	6	8	1	2	5

(A=Attribute, WA= Weightage of attribute, NA=Nature of attribute (direct =1 and indirect =0), q_j= Indifference threshold value, p_j= Strong threshold value, v_j= Veto threshold value)

Table 4.3: Concordance matrix for the alternatives

	ROT	RAT	IMT
ROT	1	0.85	0.85
RAT	0. 15	1	0.375
IMT	0.35	0.95	1

Table 4.4: Discordance index for the alternatives for transportation cost criterion

	ROT	RAT	IMT
ROT	1	0.75	0.25
RAT	0	1	0
IMT	0	0	1

Table 4.5: Discordance index for the alternatives for inventory criterion

	ROT	RAT	IMT
ROT	1	0	0
RAT	0.666667	1	0
IMT	0	0	1

Table 4.6: Discordance index for the alternatives for reliability criterion

	ROT	RAT	IMT
ROT	1	0	0
RAT	1	1	0
IMT	0	0	1

Table 4.7: Discordance index for the alternatives for flexibility criterion

	ROT	RAT	IMT
ROT	1	0	0
RAT	0.333333	1	0
IMT	0.666667	0	1

Table 4.8: Discordance index for the alternatives for transportation time criterion

	ROT	RAT	IMT
ROT	1	0	0
RAT	0.666667	1	0
IMT	0	0	1

Table 4.9: Discordance index for the alternatives for safety criterion

	ROT	RAT	IMT
ROT	1	0	0
RAT	0.666667	1	0.3333
IMT	0	0	1

Table 4.10: Discordance index for the alternatives for capacity criterion

	ROT	RAT	IMT
ROT	1	0	0
RAT	0	1	0
IMT	0	0	1

Table 4.11: Discordance index for the alternatives for density of network criterion

	ROT	RAT	IMT
ROT	1	0	0
RAT	0.5	1	0
IMT	0	0	1

Table 4.12 Discordance index for the alternatives for impact criterion

	ROT	RAT	IMT
ROT	1	0	0
RAT	0.5	1	0
IMT	0	0	1

Table 4.13: Discordance index for the alternatives for image criterion

	ROT	RAT	IMT
ROT	1	0	0
RAT	0.5	1	0
IMT	0	0	1

Table 4.14: Discordance index for the alternatives for regulation and legislation criterion

	ROT	RAT	IMT
ROT	1	0	0
RAT	0.6667	1	0
IMT	0	0	1

Table 4.15: Discordance index for the alternatives for strategic criterion

	ROT	RAT	IMT
ROT	1	0	0
RAT	0.666667	1	0
IMT	0.33333	0	1

Table 4.16: Discordance index for the alternatives for product related factors criterion

	ROT	RAT	IMT
ROT	1	0	0
RAT	0.666667	1	0
IMT	0	0	1

Table 4.17: Credibility matrix for alternatives

	ROT	RAT	IMT
ROT	1	0.85	0.875
RAT	0	1	0.375
IMT	0.35	0.95	1

Table 4.18: Ranking exploitation matrix for alternatives

	ROT	RAT	IMT
ROT	1	1	1
RAT	0	1	0
IMT	0	1	1

Table 4.19: Preorders and final ranking for alternatives

	Z_1	Z_2	Final ranking
ROT	1	1	1
RAT	3	3	3
IMT	2	2	2

4.2.1.2 Validation

Highly user-friendly software i.e. ELECTRE III is developed in VC++ to aid the user for comparison of the attributes as well as for the alternatives and for analyzing the user inputs. The mode selection factors are selected and compared with each other to determine the weight-age with respect to the case situation given in table 4.1. The best mode has to be selected from three feasible locations: road transport, rail transport and inter-modal transport. The attributes and sub -attributes are used in the ELECTRE III and their performance matrix, concordance matrix for the alternatives, discordance index for each criterion for the alternatives, credibility matrix for the alternatives, ranking exploitation matrix for the alternatives, preorders and final ranking for alternatives are given in table 4.2-4.19. From the analysis, it is clea r that the road transport is the best under the circumstances for the developed case situation.

4.2.2 Route and network

The transportation network impacts the performance of the supply chain by establishing the infrastructure within which operational transportation decision regrading scheduling and routing is made. Managers must decide on the customers to be visited by a particular vehicle and the sequence in which they will be visited. The success of this operations turns on its ability to decrease transportation and delivery cost while providing the desired level of responsiveness to the customer. Typical objectives when routing and scheduling vehicles are a combination of minimising cost by decreasing the number of vehicles needed, the total distance travelled by vehicles and the total travel time of vehicles as well as eliminating service failures such as delay in shipments. Saving matrix method is used to solve these problems as it is simple to implement and used to assign customers to vehicles even when the delivery time windows or other constraints exists. The major steps in the saving matrix method are as follows.

Step 1 Identify the distance matrix considering the distances between every pair of locations to be visited (see table 4.20).

Step 2 Identify the saving matrix (see table 4.21). The saving matrix represents the saving that accrues on consolidating two customers on a single truck. Saving may be evaluated in terms of distance, time or money.

Step 3 Assign customers to vehicles (see table 4.22). While assigning customers to vehicles, the manger attempts to maximise saving. An iterative procedure is used to make this assignment. Initially each customer is assigned to a separate route. Two routes can be combined into a feasible route, if total deliveries across both routes do not exceed the vehicle's capacity.

Step 4 Sequence customers within the routes to minimise the distance each vehicle must travel. Changing the sequence in which deliveries are made can have a significant impact on the distance travelled by vehicles. Delivery sequences are determined by obtaining an initial route sequence and then using route improvement procedures to obtain delivery sequences with a lower transportation cost.

i. The initial trip is found out by farthest insert or nearest insert or nearest neighbour or sweep (see table 4.22).

ii. Route improvement procedures start with initial trip and improve the trip to shorten its length. It can be achieved by 2-OPT method or 3-OPT method (see table 4.22). The 2-OPT procedure starts with a trip and breaks it at two places, which can be reconnected in two possible ways. The length of each reconnection is evaluated and the smaller of these two is used to define a new trip. The procedure is continued on the new trip until no further improvement results. The 3-OPT procedure is similar to 2-OPT method but only difference is that it breaks a trip at three points to obtain three paths that can be reconnected to form up eight different trips.

Highly user-friendly software, the saving matrix model is developed in VC++ to solve this problem. A case study has been considered where a supply chain manager of a distribution centre (DC) has to supply orders to 13 different retailers (R1, R2, -----, R12, R13). The order size (D units) and distance of the retailers is given in Table 4.8. The distribution centre has five trucks with maximum capacity of 200 units and it wants to assign different retailers to trucks and identify the routes to trucks with a goal of minimising number of trucks and distance travelled. It is solved by saving matrix model and results are shown in table 4.22. The results show that four trucks have to be used. Retailers 2 and 9 have to be assigned to truck 1 and it has to travel like DC -R2-R9-DC. Similarly for other trucks results are shown in table 4.22.

Table 4.20: Distance matrix (km) for saving matrix model

	DC	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 12	R13	D (units)
DC	0														48
R 1	12	0													36
R 2	8	9	0												43
R 3	17	8	10	0											92
R 4	15	9	8	4	0										57
R 5	15	17	9	14	11	0									

R 6	20	23	15	20	16	6	0								16
R 7	17	22	13	20	16	5	4	0							56
R 8	8	17	9	19	16	11	14	10	0						30
R 9	6	18	12	22	20	17	20	16	6	0					57
R 10	16	23	14	22	19	9	8	4	8	14	0				47
R 11	21	28	18	26	22	11	7	6	13	19	5	0			91
R 12	11	22	14	26	21	14	16	12	5	7	9	13	0		55
R13	15	27	20	30	28	22	23	20	12	9	16	20	8	0	38

Table 4.21: Saving matrix (km) for saving matrix model

	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 12	R13
R 1	0												
R 2	11	0											
R 3	21	15	0										
R 4	18	15	28	0									
R 5	10	14	18	19	0								
R 6	9	13	17	19	29	0							
R 7	7	12	14	16	27	33	0						
R 8	3	7	6	7	12	14	15	0					
R 9	0	2	1	1	4	6	7	8	0				
R 10	5	10	11	12	12	28	29	16	8	0			
R 11	5	11	12	14	25	34	32	16	8	32	0		
R 12	1	5	4	5	12	15	16	14	10	18	19	0	
R13	0	3	2	2	8	12	12	11	12	15	16	18	0

Table 4.22: Results of saving matrix method

Assignment of customers to vehicle	Initial trip for {5,10,12,13}	Delivery schedule using 2-OPT or 3-OPT
T1= {2,9}	Farthest insert = {DC,5,1012,13,DC}	T1= {DC,2,9,DC}
T2= {1,3,4}	Nearest insert= {DC, 5,10,12,13, DC}	T2={DC,1,3,4,DC}
T3={6,7,8,8,11}	Nearest neighbour={DC,12,10,5,13,DC}	T3={DC,8,11,6,7,DC}
T4={5,10,12,13}	Sweep={DC,5,10,12,13,DC}	T4={DC, 5,10,12,13,DC}

4.2.3 Logistics: outsourcing or insourcing

Literature on supply chain management recommends that firms should concentrate on their core competencies and outsource other activities (Handfield and Nichols, 1999). For most of the firms, logistics is not considered to be a core competency. Prahalad and Hamel (1990) define core competence as "the collective learning in the organization, especially how to coordinate diverse production skills and integrate multiple streams of technologies". A manager responsible for making 'logistics outsourcing' decision must develop a true sense of what the core competence of the organization is and whether the service under consideration is an integral part of that core competence. A key service that is closely interrelated with the firms competence would more likely to be reflected in a favourable 'insourcing' decision, rather than an 'outsourcing' decision. If a firm errs and mistakenly outsourcers a core competence, it may loose its competitive advantage. From the literature the following characteristics of core competencies have been identified:

- Rare (Barney, 1986, 1991, 1997)
- Unimitable, lack of transferability, and replicability (Barney 1986, 1991; Dierickx and Cool, 1989; Prahalad and Hamel, 1990; Grant, 1991; Tampoe, 1994)
- Add significantly to the ultimate value of the product or service (Barney, 1986, 1991, 1997; Synder and Ebeling, 1992; Grant, 1991; Tampoe, 1994)
- Have potential to support multiple products or services (Prahalad and Hamel, 1990; Synder and Ebeling, 1992)
- Represent a unique capability that produces long lasting competitive advantage (Synder and Ebeling, 1992; Tampoe, 1994)

- Essential to corporate survival (Tampoe, 1994)
- Invisible to competitors (Tampoe, 1994)
- Greater than the competence of an individual (Tampoe, 1994)
- Essential to the strategic vision and decisions of the organization (Tampoe, 1994)
- There are a limited number within each organization (Tampoe, 1994)
- Durable (Grant, 1991)
- Manifest differently in organizations (Turner and Crawford, 1994)

Therefore a core competency is not just something a company does well but it is a combination of capabilities that is unique (a strong differentiator for your business), is durable (hard for your competitors to imitate), and is extensive (delivering significant value to your company). For most of the firms, transportation is not considered to be a core competency. Thus transportation activities are often subject to outsourcing. The range of effective logistics outsourcing strategies spans the continuum from traditional outsourcing of transportation or warehousing services to complete outsourcing of all logistics activities. Research indicates that warehousing, outbound transportation and freight bill payment and/or auditing are the most frequently outsourced logistics activities. Other logistics services that are gaining attention and growing in popularity include packaging and assembly operations, cross-docking, merge-in-transit, inbound transportation and freight consolidation.

Strategic objective of logistics outsourcing

Most companies justify their choice to logistics outsourcing for more than one of the following primary reasons:

- Focus on core business
- Improved capital utilisation

- Supply chain cost reduction
- Improved customer service

Focus on core business: Today, many companies are outsourcing some of their logistics/supply chain functions to outside firms as they wish to focus on their core business or because another company can provide a competitive advantage through that area. It is usually a competitive advantage for any company to concentrate on what they do best, eliminating from direct control those activities which can be done more effectively elsewhere. For most organizations, logistics activities fall into that category.

Improved capital utilisation: Business is focused on increasing short-term profitability and return on capital. Asset-based non-core activities are therefore, high priority targets for outsourcing. Expanding on this situation is the recognition that corporate asset turnover (as measured by return on assets, equity, or investment) grows substantially when facilities, equipment, and inventory are removed from the equation, and when significant investments in technology hardware and software can be avoided.

Supply chain cost reduction: The reduction of supply chain costs is probably the most visible (though not the most important) value. Even though each supply chain will have different levels of expertise and therefore different expectations from their third party logistics provider (3PL/Carrier) service providers, the critical focus in procuring logistics services is the emphasis on overall value, rather than solely on a single-dimension attribute such as cost or service. Leading companies who use 3PL services are seeking performance levels where the overall net benefits exceed the amount paid to the 3PL. In addition to the primary capital and cost related reasons, leading firms have incorporated incentive or performance-based 3PL contracts that drive continuous improvement.

Improved customer service: According to Flint *et al.* (2001) businesses have moved beyond viewing logistics as merely an area for cost improvements to viewing logistics as a key source of competitive advantage within a firm's total market efforts. The authors state that customer service has been a key focal area of research in the logistics discipline for several years. The research shows that logistics service capabilities can be leveraged to create customer and supplier value through service performance, increased market share, enable mass customization, create effective customer response-based systems, positively affect customer satisfaction and, in turn corporate performance, provide a differentiating competitive advantage and segment customers.

4.2.4 Development of PROMETHEE II for selection of carrier

There are two key players in any transportation that takes place within a supply chain (i.e. shipper and carrier). The shipper is the party that requires the movement of the product between two points in the supply chain, and carrier is the party that moves or transports the product. For example, when Dell uses UPS to ship its computers from the factory to the customer, Dell is shipper and UPS is the carrier (Chopra and Meindl, 2003). In particular, an economical transportation system can contribute to a stronger competitive position in the marketplace and reduced prices for goods. This is because it has been estimated that, on average, 3.5 percent of a manufacturer's sales costs and 40 percent to 60 percent of total logistics costs are devoted to transportation (Weil, 1998). Not all shippers consider price is the determining element in carrier selection (Harrington, 1996). For example, it was suggested that quality service should be a higher priority than low cost in choosing carriers (Thuermer, 1992). Some purchasing professionals involved in transportation and logistics services cite on-time pick-up and delivery as the single most important carrier selection factor (Milligan, 1999). In contrast with the aforementioned studies, many researchers place much emphasis on approaches to lowering logistical costs. These include designing vehicle-routing algorithms (Pooley, 1992), applying for product reclassification (Flynn, 1987), and coordinating shipping and receiving schedules (McDonald, 1993). In addition, the increasing need for using software (Andel, 1996), the Internet and wireless communications (Yen and Chou, 2000) to curtail transportation costs has been well recognized. The carrier selection decision is a process of purchasing the services of a carrier to provide link services between logistics node. Carrier selection logically follows mode selection. The selected carrier directly affects transportation cost, service level, inventory level and service quality which has impact on the demand for the company's product. Before making a long-term commitment of traffic, the traffic manager has to evaluate the strengths and weakness of carriers to ensure that only qualified carriers participate. Qualified carriers will have the operational (i.e. it includes the carrier's record and reputation, availability of special purpose vehicles and technological capability) and financial capability as well as business integrity to meet shipper's needs. Therefore, while taking decision regarding carrier selection both the qualitative and quantitative factors have to be considered.

Company X is involved in an automotive production. Most of the products are world-class and supply chain is a key competitive factor in the business. The logistics executives now face the problem to develop the competitive supply chain. Based on preliminary analysis, the logistics executives identified three possible carriers i.e. carrier A, carrier B and carrier C. Among these three carriers, the best carrier has to be selected. A thorough analysis of the problem is required along with the identification of the important attributes involved. The selection of the attributes is determined through literature survey and discussions held with experts. The attributes used in the PROMETHEE II for selection of carrier are as follows

- Price [PRC]
- Price commensurate with service level [PSL]
- Reliability [REL]
- Flexibility [FLX]
- Willingness of the carrier to negotiate service charges [WNS]
- Order cycle time [OCT]
- Transit time [TTE]
- Customer support [CSU]
- Range of services [ROS]
- Area coverage [ACO]
- Management quality [MAQ]
- Global capabilities [GLC]
- Financial stability [FIS]
- Government regulations and insurance policies [GRP]
- Special expertise [SPE]
- Maintenance systems [MAS]
- Reverse logistics [REL]
- Compatibility [COM]
- Security [SEC]
- Technical competence [TEC]
- Product related factors [PRF]
- Adoption to new technology [ANT]
- Company image and goodwill [CIG]

- Early notification of disruptions [END]
- Proximity to the company/location [PCL]
- Information infrastructure [IIT]
- Information sharing [INS]
- Shipment tracking [SHT]
- Documentation [DOC]
- System capabilities [SYC]
- Claims management [CLM]
- Continuous improvement [CIM]

PROMETHEE is a multi-criteria decision method developed by Brans *et al.* (1984) and Brans and Vincke (1985). It is an outranking method where the intensity of the preference for alternative a over alternative b with regards to each criterion j is measured in terms of a preference function $P_j(a,b)$. Brans *et al.* (1986) proposed six possible types of generalised criterion (see table 4.23) as

- Type I (Usual criterion): It is basic type without any threshold and very seldom used.
- Type II (U-shape criterion): It uses a single indifference threshold and mostly used with qualitative criteria.
- Type III (V-shape criterion): It uses a single preference threshold and often used with quantitative criteria.
- Type IV (Level criterion): It is similar to U-Shape but with an additional preference threshold and used with qualitative criteria.

- Type V (V-shape criterion with indifference criterion): It is similar to V-Shape but with an additional indifference threshold and often used with quantitative criteria.
- Type VI (Gaussian criterion): It is seldom used.

In order to define these functions, one or two threshold is to be fixed:

- Indifference threshold (q): It is the lowest value of $d_j(a,b)$ below which the decision maker considers, there is indifference between 'a' and 'b'.
- Strict preference threshold (p): It is the lowest value of $d_j(a,b)$ below which the decision maker considers, there is a strict preference of 'a' and 'b'.
- Standard deviation (σ): It is well known parameter directly connected with standard deviation of a normal distribution.

A weighted average of the preference functions is calculated to obtain a rank ordering of the alternatives. 'PROMETHEE I' provides a partial pre-ordering of the alternatives through a pair wise dominance comparison of positive and negative outranking flows. 'PROMETHEE II' provides a complete pre-ordering through a comparison of net outranking flows.

4.2.4.1 Algorithm

The steps to follow in PROMTHEE II are:

Step 1 Define the problem and determine the objectives.

Step 2 Identify the alternatives (a_i) available (The alternatives are: Carrier A, Carrier B, Carrier C, and Carrier D).

Step 3 Determine the attributes/criteria/performance indicators that govern the problem.

Step 4 Classify the attributes/criteria/performance indicators into direct (performance grows while measure increases) and indirect categories (performance grows while measure decreases) (see table 4.24).

Step 5 Choose the preference function (i.e. Type I: Usual criterion, Type II: U-shape criterion, Type III: V-shape criterion, Type IV: Level criterion, Type V: V-shape criterion with indifference criterion, Type VI: Gaussian criterion) for each criterion. (Steps 3-5 are shown in table 4.23)

Step 6 Form the performance matrix, i.e., co-efficient g_{ij} related to the attribute/ criterion/ performance indicator g_j (j=1, 2, 3 ….J) for the alternative a_i (i=1,2,3………I).

Step 7 Quantify the qualitative attributes using the scale of 1 to 10, where 1 means very low, 3 means low, 5 means medium, 7 means high, and 9 means very high.

Step 8 Absolute weightage w_j on a suitable scale (say 1 to 10) is assigned for each attribute/criterion/performance indicator reflecting the normative judgment of the decision maker.

Step 9 Obtain the relative weight-age for each attribute/criterion/performance indicator (c_j) from absolute weightage w_j:

$$W_j = \frac{w_j}{\sum w_j} \quad \text{such that } \sum W_j = 1$$

Step10 Form the threshold matrix using the strong preference threshold value (p_j) and indifference threshold value (q_j) for each attributes/

criteria/performance indicators if required depending upon the preference function (Steps 6-10 are shown in table 4.25).

Step 11 Calculate the preference index for each alternative over all criteria (see table 4.26-4.37). The preference index (see table 4.38) is defined as:

$$\pi(a_1, a_2) = \sum_{j=1}^{j=J} W_j \times P_j(a_1, a_2)$$

W_j refers to the weight assigned to the criterion j and $P_j(d_j(a_1, a_2))$ refers to the value of the preference function accorded to the difference between the evaluations of the alternatives a_1 and a_2 on the criterion j $(d_j(a_1, a_2) = g_j(a_1) - g_j(a_2))$.

Step 12 Compute positive (where alternative is dominating) and negative (where alternative is dominated) outranking flows for each alternative as indicated below (see table 4.39):

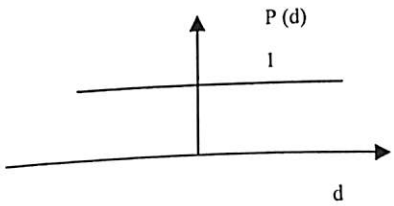
$$\Theta^+(a_1) = \sum_{i=1}^{I} \pi(a_1, a_i) \qquad \Theta^-(a_1) = \sum_{i=1}^{I} \pi(a_1, a_i)$$

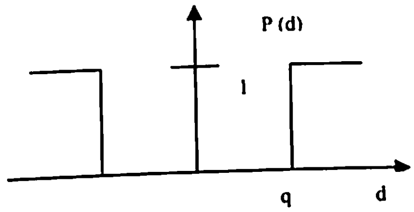
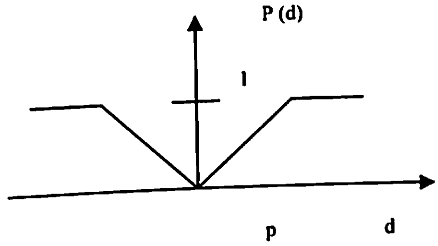
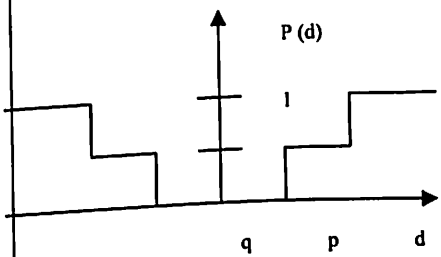
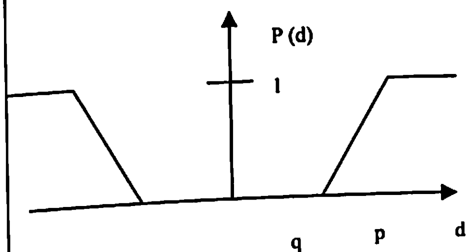
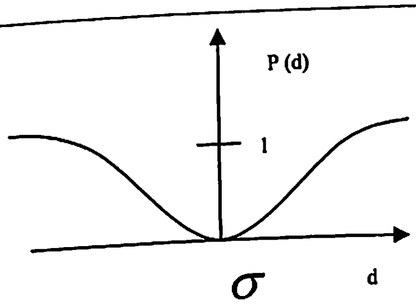
Step 13 Compute the net flow as indicated below (see table 4.39):

$$\Theta(a_1) = \Theta^+(a_1) - \Theta^-(a_1)$$

Step 14 Rank the alternatives by their net flow (see table 4.39).

Table 4.23: Six possible types of generalised criteria

Generalised criterion type	Preference function $P(d)$
Type I: Usual criterion $P(d) = \begin{cases} 0 & d = 0 \\ 1 & \lvert d \rvert = 1 \end{cases}$	

Type II: U-shape criterion $P(d)=\begin{cases}0 & \lvert d\rvert \le q\\ 1 & \lvert d\rvert > q\end{cases}$	
Type III: V-shape criterion $P(d)=\begin{cases}\dfrac{\lvert d\rvert}{p} & \lvert d\rvert \le p\\ 1 & \lvert d\rvert > p\end{cases}$	
Type IV: Level criterion $P(d)=\begin{cases}0 & \lvert d\rvert \le q\\ \dfrac{1}{2} & q<\lvert d\rvert \le p\\ 1 & \lvert d\rvert > p\end{cases}$	
Type V: V-shape criterion with indifference criterion $P(d)=\begin{cases}0 & \lvert d\rvert \le q\\ \dfrac{\lvert d\rvert-q}{p-q} & q<\lvert d\rvert \le p\\ 1 & \lvert d\rvert > p\end{cases}$	
Type VI: Gaussian criterion $P(d)=1-e^{\left(-d^2/2\sigma^2\right)}$	

4.2.4.2 Validation

Highly user-friendly software i.e. PROMTHEE II is developed in VC++ to aid the user for comparison of the attributes as well as for the alternatives and for analyzing the user inputs. The carrier selection factors are compared with each other to determine the weight-age with respect to the case situation given in table 4.1. The best carrier has to be selected from three feasible carriers: Carrier A, Carrier B, Carrier C and Carrier D. The attributes used in the PROMTHEE II, their performance matrix, the value of preference function over all attributes for all combination of alternatives and preference index of alternatives are given in t able 4.26-4.38. Positive flow, negative flow and net flow of the alternatives are shown in figure 4.2. The rank of the alternatives is also shown in table 4.39. From the analysis, it is clear that the Carrier A is the best under the circumstances of the developed case situation.

Table 4.24: Attributes/ criteria/performance indicators

Attributes/criteria/performance indicators	Notation	Preference function	Direct/ Indirect
Price	[PRC]	Type V	Indirect
Price commensurate with service level	[PSL]	Type II	Indirect
Reliability	[REL]	Type II	Direct
Flexibility	[FLX]	Type II	Direct
Willingness of the carrier to negotiate service charges	[WNS]	Type II	Direct
Order cycle time	[OCT]	Type V	Direct
Transit time	[TTE]	Type III	Indirect
Customer support	[CSU]	Type IV	Direct
Range of services	[ROS]	Type IV	Direct
Area coverage	[ACO]	Type II	Direct
Management quality	[MAQ]	Type II	Direct
Global capabilities	[GLC]	Type IV	Direct

Financial stability	[FIS]	Type II	Direct
Government regulations and insurance policies	[GRP]	Type IV	Direct
Special expertise	[SPE]	Type IV	Direct
Maintenance systems	[MAS]	Type II	Direct
Reverse logistics	[REL]	Type IV	Direct
Compatibility	[COM]	Type II	Direct
Security	[SEC]	Type IV	Direct
Technical competence	[TEC]	Type V	Direct
Product related factors	[PRF]	Type IV	Direct
Adoption to new technology	[ANT]	Type IV	Direct
Company image and goodwill	[CIG]	Type II	Direct
Early notification of disruptions	[END]	Type III	Indirect
Proximity to the company/location	[PCL]	Type III	Indirect
Information infrastructure	[IIT]	Type IV	Direct
Information sharing	[INS]	Type IV	Direct
Shipment tracking	[SHT]	Type II	Direct
Documentation	[DOC]	Type II	Direct
System capabilities	[SYC]	Type V	Direct
Claims management	[CLM]	Type II	Direct
Continuous improvement	[CIM]	Type IV	Direct

Table 4.25: Performance matrix

Notation	w_j	q_j	p_j	Carrier A	Carrier B	Carrier C	Carrier D
[PRC]	9	2	9	100	92	88	110
[PSL]	8	1	0	8	5	6	9
[REL]	9	2	0	9	4	7	5
[FLX]	7	2	0	5	6	9	7
[WNS]	7	2	0	7	9	6	5
[OCT]	6.5	2	5	24	18	10	15
[TTE]	7.5	0	1	2	3	5	2.5
[CSU]	7.5	1	2	9	5	8	6
[ROS]	8	1	2	5	3	7	9
[ACO]	9	1	0	9	5	8	6
[MAQ]	8	1	0	8	5	7	9
[GLC]	9	1	3	9	5	4	7
[FIS]	7	2	0	9	8	5	7
[GRP]	8	1	2	7	5	8	9
[SPE]	7.5	1	2	9	5	6	8
[MAS]	8	1	0	9	5	7	6
[REL]	7	1	3	5	7	9	7
[COM]	8.5	2	0	6	5	9	8
[SEC]	7	1	3	5	7	7	9
[TEC]	7	10	40	50	74	60	500
[PRF]	7	1	2	8	5	6	9
[ANT]	7.5	1	3	9	6	7	5
[CIG]	8	2	0	9	7	6	5
[END]	7	0	1	1.15	2	2.2	1
[PCL]	9	0	0.2	0.5	0.75	1	0.4
[IIT]	8	1	3	9	5	8	4
[INS]	8	1	3	9	5	7	4
[SHT]	7	2	0	7	9	8	6
[DOC]	7	2	0	9	6	5	7
[SYC]	8	1	2	9	5	7	6
[CLM]	7.5	2	0	9	5	6	7
[CIM]	9	1	2	8	6	5	7

Table 4.26: The value of preference function over all attributes for alternatives a1 and a2

P1(a1,a2)= 0.0000
P2(a1,a2)= 0.0000
P3(a1,a2)= 1.0000
P4(a1,a2)= 0.0000
P5(a1,a2)= 0.0000
P6(a1,a2)= 1.0000
P7(a1,a2)= 1.0000
P8(a1,a2)= 1.0000
P9(a1,a2)= 0.5000
P10(a1,a2)= 1.0000
P11(a1,a2)= 1.0000
P12(a1,a2)= 1.0000
P13(a1,a2)= 0.0000
P14(a1,a2)= 0.5000
P15(a1,a2)= 1.0000
P16(a1,a2)= 1.0000
P17(a1,a2)= 0.0000
P18(a1,a2)= 0.0000
P19(a1,a2)= 0.0000
P20(a1,a2)= 0.0000
P21(a1,a2)= 1.0000
P22(a1,a2)= 0.5000
P23(a1,a2)= 0.0000
P24(a1,a2)= 0.8500
P25(a1,a2)= 1.0000
P26(a1,a2)= 1.0000
P27(a1,a2)= 1.0000
P28(a1,a2)= 0.0000
P29(a1,a2)= 1.0000
P30(a1,a2)= 1.0000
P31(a1,a2)= 1.0000
P32(a1,a2)= 0.5000

Table 4.27: The value of preference function over all attributes for alternatives a1 and a3

P1(a1,a3)= 0.0000
P2(a1,a3)= 0.0000
P3(a1,a3)= 0.0000
P4(a1,a3)= 0.0000
P5(a1,a3)= 0.0000
P6(a1,a3)= 1.0000
P7(a1,a3)= 1.0000
P8(a1,a3)= 0.0000
P9(a1,a3)= 0.0000
P10(a1,a3)= 0.0000
P11(a1,a3)= 0.0000
P12(a1,a3)= 1.0000
P13(a1,a3)= 1.0000
P14(a1,a3)= 0.0000
P15(a1,a3)= 1.0000
P16(a1,a3)= 1.0000
P17(a1,a3)= 0.0000
P18(a1,a3)= 0.0000
P19(a1,a3)= 0.0000
P20(a1,a3)= 0.0000
P21(a1,a3)= 0.5000
P22(a1,a3)= 0.5000
P23(a1,a3)= 1.0000
P24(a1,a3)= 1.0000
P25(a1,a3)= 1.0000
P26(a1,a3)= 0.0000
P27(a1,a3)= 0.5000
P28(a1,a3)= 0.0000
P29(a1,a3)= 1.0000
P30(a1,a3)= 1.0000
P31(a1,a3)= 1.0000
P32(a1,a3)= 1.0000

Table 4.28: The value of preference function over all attributes for alternatives a1 and a4

P1(a1,a4)= 1.0000
P2(a1,a4)= 0.0000
P3(a1,a4)= 1.0000
P4(a1,a4)= 0.0000
P5(a1,a4)= 0.0000
P6(a1,a4)= 1.0000
P7(a1,a4)= 0.5000
P8(a1,a4)= 1.0000
P9(a1,a4)= 0.0000
P10(a1,a4)= 1.0000
P11(a1,a4)= 0.0000
P12(a1,a4)= 0.5000
P13(a1,a4)= 0.0000
P14(a1,a4)= 0.0000
P15(a1,a4)= 0.0000
P16(a1,a4)= 1.0000
P17(a1,a4)= 0.0000
P18(a1,a4)= 0.0000
P19(a1,a4)= 0.0000
P20(a1,a4)= 0.0000
P21(a1,a4)= 0.0000
P22(a1,a4)= 1.0000
P23(a1,a4)= 1.0000
P24(a1,a4)= 0.0000
P25(a1,a4)= 0.0000
P26(a1,a4)= 1.0000
P27(a1,a4)= 1.0000
P28(a1,a4)= 0.0000
P29(a1,a4)= 0.0000
P30(a1,a4)= 1.0000
P31(a1,a4)= 0.0000
P32(a1,a4)= 0.0000

Table 4.29: The value of preference function over all attributes for alternatives a2 and a1

P1(a2,a1)= 0.8571
P2(a2,a1)= 1.0000
P3(a2,a1)= 0.0000
P4(a2,a1)= 0.0000
P5(a2,a1)= 0.0000
P6(a2,a1)= 0.0000
P7(a2,a1)= 0.0000
P8(a2,a1)= 0.0000
P9(a2,a1)= 0.0000
P10(a2,a1)= 0.0000
P11(a2,a1)= 0.0000
P12(a2,a1)= 0.0000
P13(a2,a1)= 0.0000
P14(a2,a1)= 0.0000
P15(a2,a1)= 0.0000
P16(a2,a1)= 0.0000
P17(a2,a1)= 0.5000
P18(a2,a1)= 0.0000
P19(a2,a1)= 0.5000
P20(a2,a1)= 0.4667
P21(a2,a1)= 0.0000
P22(a2,a1)= 0.0000
P23(a2,a1)= 0.0000
P24(a2,a1)= 0.0000
P25(a2,a1)= 0.0000
P26(a2,a1)= 0.0000
P27(a2,a1)= 0.0000
P28(a2,a1)= 0.0000
P29(a2,a1)= 0.0000
P30(a2,a1)= 0.0000
P31(a2,a1)= 0.0000
P32(a2,a1)= 0.0000

Table 4.30: The value of preference function over all attributes for alternatives a2 and a3

P1(a2,a3)= 0.0000
P2(a2,a3)= 0.0000
P3(a2,a3)= 0.0000
P4(a2,a3)= 0.0000
P5(a2,a3)= 1.0000
P6(a2,a3)= 1.0000
P7(a2,a3)= 1.0000
P8(a2,a3)= 0.0000
P9(a2,a3)= 0.0000
P10(a2,a3)= 0.0000
P11(a2,a3)= 0.0000
P12(a2,a3)= 0.0000
P13(a2,a3)= 1.0000
P14(a2,a3)= 0.0000
P15(a2,a3)= 0.0000
P16(a2,a3)= 0.0000
P17(a2,a3)= 0.0000
P18(a2,a3)= 0.0000
P19(a2,a3)= 0.0000
P20(a2,a3)= 0.1333
P21(a2,a3)= 0.0000
P22(a2,a3)= 0.0000
P23(a2,a3)= 0.0000
P24(a2,a3)= 0.2000
P25(a2,a3)= 1.0000
P26(a2,a3)= 0.0000
P27(a2,a3)= 0.0000
P28(a2,a3)= 0.0000
P29(a2,a3)= 0.0000
P30(a2,a3)= 0.0000
P31(a2,a3)= 0.0000
P32(a2,a3)= 0.0000

Table 4.31: The value of preference function over all attributes for alternatives a2 and a4

P1(a2,a4)= 1.0000
P2(a2,a4)= 1.0000
P3(a2,a4)= 0.0000
P4(a2,a4)= 0.0000
P5(a2,a4)= 1.0000
P6(a2,a4)= 0.3333
P7(a2,a4)= 0.0000
P8(a2,a4)= 0.0000
P9(a2,a4)= 0.0000
P10(a2,a4)= 0.0000
P11(a2,a4)= 0.0000
P12(a2,a4)= 0.0000
P13(a2,a4)= 0.0000
P14(a2,a4)= 0.0000
P15(a2,a4)= 0.0000
P16(a2,a4)= 0.0000
P17(a2,a4)= 0.0000
P18(a2,a4)= 0.0000
P19(a2,a4)= 0.0000
P20(a2,a4)= 0.0000
P21(a2,a4)= 0.0000
P22(a2,a4)= 0.0000
P23(a2,a4)= 0.0000
P24(a2,a4)= 0.0000
P25(a2,a4)= 0.0000
P26(a2,a4)= 0.0000
P27(a2,a4)= 0.0000
P28(a2,a4)= 1.0000
P29(a2,a4)= 0.0000
P30(a2,a4)= 0.0000
P31(a2,a4)= 0.0000
P32(a2,a4)= 0.0000

Table 4.32: The value of preference function over all attributes for alternatives a3 and a1

P1(a3,a1)= 1.0000
P2(a3,a1)= 1.0000
P3(a3,a1)= 0.0000
P4(a3,a1)= 1.0000
P5(a3,a1)= 0.0000
P6(a3,a1)= 0.0000
P7(a3,a1)= 0.0000
P8(a3,a1)= 0.0000
P9(a3,a1)= 0.5000
P10(a3,a1)= 0.0000
P11(a3,a1)= 0.0000
P12(a3,a1)= 0.0000
P13(a3,a1)= 0.0000
P14(a3,a1)= 0.0000
P15(a3,a1)= 0.0000
P16(a3,a1)= 0.0000
P17(a3,a1)= 1.0000
P18(a3,a1)= 1.0000
P19(a3,a1)= 0.5000
P20(a3,a1)= 0.0000
P21(a3,a1)= 0.0000
P22(a3,a1)= 0.0000
P23(a3,a1)= 0.0000
P24(a3,a1)= 0.0000
P25(a3,a1)= 0.0000
P26(a3,a1)= 0.0000
P27(a3,a1)= 0.0000
P28(a3,a1)= 0.0000
P29(a3,a1)= 0.0000
P30(a3,a1)= 0.0000
P31(a3,a1)= 0.0000
P32(a3,a1)= 0.0000

Table 4.33: The value of preference function over all attributes for alternatives a3 and a2

P1(a3,a2)= 0.2857
P2(a3,a2)= 0.0000
P3(a3,a2)= 1.0000
P4(a3,a2)= 1.0000
P5(a3,a2)= 0.0000
P6(a3,a2)= 0.0000
P7(a3,a2)= 0.0000
P8(a3,a2)= 1.0000
P9(a3,a2)= 1.0000
P10(a3,a2)= 1.0000
P11(a3,a2)= 1.0000
P12(a3,a2)= 0.0000
P13(a3,a2)= 0.0000
P14(a3,a2)= 1.0000
P15(a3,a2)= 0.0000
P16(a3,a2)= 1.0000
P17(a3,a2)= 0.5000
P18(a3,a2)= 1.0000
P19(a3,a2)= 0.0000
P20(a3,a2)= 0.0000
P21(a3,a2)= 0.0000
P22(a3,a2)= 0.0000
P23(a3,a2)= 0.0000
P24(a3,a2)= 0.0000
P25(a3,a2)= 0.0000
P26(a3,a2)= 0.5000
P27(a3,a2)= 0.5000
P28(a3,a2)= 0.0000
P29(a3,a2)= 0.0000
P30(a3,a2)= 1.0000
P31(a3,a2)= 0.0000
P32(a3,a2)= 0.0000

Table 4.34: The value of preference function over all attributes for alternatives a3 and a4

P1(a3,a4)= 1.0000
P2(a3,a4)= 1.0000
P3(a3,a4)= 0.0000
P4(a3,a4)= 0.0000
P5(a3,a4)= 0.0000
P6(a3,a4)= 0.0000
P7(a3,a4)= 0.0000
P8(a3,a4)= 0.5000
P9(a3,a4)= 0.0000
P10(a3,a4)= 1.0000
P11(a3,a4)= 0.0000
P12(a3,a4)= 0.0000
P13(a3,a4)= 0.0000
P14(a3,a4)= 0.0000
P15(a3,a4)= 0.0000
P16(a3,a4)= 0.0000
P17(a3,a4)= 0.5000
P18(a3,a4)= 0.0000
P19(a3,a4)= 0.0000
P20(a3,a4)= 0.0000
P21(a3,a4)= 0.0000
P22(a3,a4)= 0.5000
P23(a3,a4)= 0.0000
P24(a3,a4)= 0.0000
P25(a3,a4)= 0.0000
P26(a3,a4)= 1.0000
P27(a3,a4)= 0.5000
P28(a3,a4)= 0.0000
P29(a3,a4)= 0.0000
P30(a3,a4)= 0.0000
P31(a3,a4)= 0.0000
P32(a3,a4)= 0.0000

Table 4.35: The value of preference function over all attributes for alternatives a4 and a1

P1(a4,a1)= 0.0000
P2(a4,a1)= 0.0000
P3(a4,a1)= 0.0000
P4(a4,a1)= 0.0000
P5(a4,a1)= 0.0000
P6(a4,a1)= 0.0000
P7(a4,a1)= 0.0000
P8(a4,a1)= 0.0000
P9(a4,a1)= 1.0000
P10(a4,a1)= 0.0000
P11(a4,a1)= 0.0000
P12(a4,a1)= 0.0000
P13(a4,a1)= 0.0000
P14(a4,a1)= 0.5000
P15(a4,a1)= 0.0000
P16(a4,a1)= 0.0000
P17(a4,a1)= 0.5000
P18(a4,a1)= 0.0000
P19(a4,a1)= 1.0000
P20(a4,a1)= 1.0000
P21(a4,a1)= 0.0000
P22(a4,a1)= 0.0000
P23(a4,a1)= 0.0000
P24(a4,a1)= 0.1500
P25(a4,a1)= 0.5000
P26(a4,a1)= 0.0000
P27(a4,a1)= 0.0000
P28(a4,a1)= 0.0000
P29(a4,a1)= 0.0000
P30(a4,a1)= 0.0000
P31(a4,a1)= 0.0000
P32(a4,a1)= 0.0000

Table 4.36: The value of preference function over all attributes for alternatives a4 and a2

P1(a4,a2)= 0.0000
P2(a4,a2)= 0.0000
P3(a4,a2)= 0.0000
P4(a4,a2)= 0.0000
P5(a4,a2)= 0.0000
P6(a4,a2)= 0.0000
P7(a4,a2)= 0.5000
P8(a4,a2)= 0.0000
P9(a4,a2)= 1.0000
P10(a4,a2)= 0.0000
P11(a4,a2)= 1.0000
P12(a4,a2)= 0.5000
P13(a4,a2)= 0.0000
P14(a4,a2)= 1.0000
P15(a4,a2)= 1.0000
P16(a4,a2)= 0.0000
P17(a4,a2)= 0.0000
P18(a4,a2)= 1.0000
P19(a4,a2)= 0.5000
P20(a4,a2)= 1.0000
P21(a4,a2)= 1.0000
P22(a4,a2)= 0.0000
P23(a4,a2)= 0.0000
P24(a4,a2)= 1.0000
P25(a4,a2)= 1.0000
P26(a4,a2)= 0.0000
P27(a4,a2)= 0.0000
P28(a4,a2)= 0.0000
P29(a4,a2)= 0.0000
P30(a4,a2)= 0.0000
P31(a4,a2)= 0.0000
P32(a4,a2)= 0.0000

Table 4.37: The value of preference function over all attributes for alternatives a4 and a3

P1(a4,a3)= 0.0000
P2(a4,a3)= 0.0000
P3(a4,a3)= 0.0000
P4(a4,a3)= 0.0000
P5(a4,a3)= 0.0000
P6(a4,a3)= 1.0000
P7(a4,a3)= 1.0000
P8(a4,a3)= 0.0000
P9(a4,a3)= 0.5000
P10(a4,a3)= 0.0000
P11(a4,a3)= 1.0000
P12(a4,a3)= 0.5000
P13(a4,a3)= 0.0000
P14(a4,a3)= 0.0000
P15(a4,a3)= 0.5000
P16(a4,a3)= 0.0000
P17(a4,a3)= 0.0000
P18(a4,a3)= 0.0000
P19(a4,a3)= 0.5000
P20(a4,a3)= 1.0000
P21(a4,a3)= 1.0000
P22(a4,a3)= 0.0000
P23(a4,a3)= 0.0000
P24(a4,a3)= 1.0000
P25(a4,a3)= 1.0000
P26(a4,a3)= 0.0000
P27(a4,a3)= 0.0000
P28(a4,a3)= 0.0000
P29(a4,a3)= 0.0000
P30(a4,a3)= 0.0000
P31(a4,a3)= 0.0000
P32(a4,a3)= 0.5000

Table 4.38: Preference index of the alternatives

$\pi(a_1,a_2)$	0.59839
$\pi(a_1,a_3)$	0.45171
$\pi(a_1,a_4)$	0.389336
$\pi(a_2,a_1)$	0.104551
$\pi(a_2,a_3)$	0.158283
$\pi(a_2,a_4)$	0.133467
$\pi(a_3,a_1)$	0.189135
$\pi(a_3,a_2)$	0.382581
$\pi(a_3,a_4)$	0.197183
$\pi(a_4,a_1)$	0.141046
$\pi(a_4,a_2)$	0.328974
$\pi(a_4,a_3)$	0.290744

Table 4.39: Positive flow, negative flow, net flow and rank of the alternatives

	Θ^+	Θ^-	Θ	Rank of the alternative
Carrier A	0.48	0.145	0.335	1
Carrier B	0.13	0.44	-0.21	4
Carrier C	0.26	0.3	-0.04	3
Carrier D	0.25	0.24	0.01	2

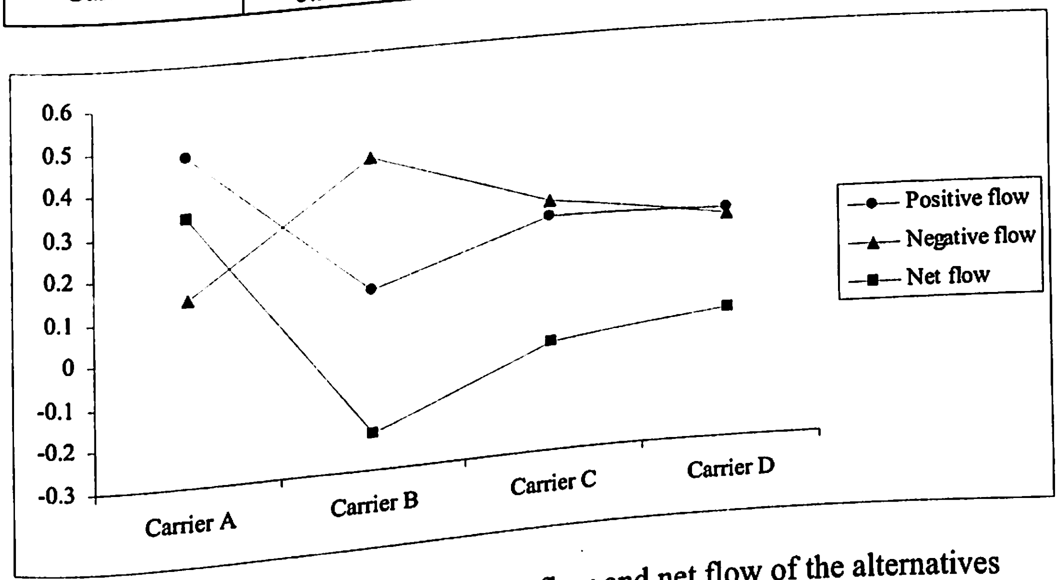


Figure 4.2: Positive flow, negative flow and net flow of the alternatives

4.3 Conclusions

In this chapter decision support system framework is developed for design of transportation driver in SCM. The focus is given on selection of transportation mode, route and network, logistics: outsourcing or insourcing and selection of carrier. For selection of mode, a decision support system i.e. ELECTRE III is developed and it is validated by considering a case situation. Detail discussion on core competency has been carried out and it is concluded that for the most of the organisations, logistics does not come under core competency. Therefore logistics should be outsourced. For logistics outsourcing, carrier selection is essential. Hence, a decision support system i.e. PROMTHEE II is developed for selection of carrier. The decision support system framework for design of transportation driver is validated with a case situation.

References

[1] ABDINNOUR H. S. (1999), "Network Design in Supply Chain Management", Available From: http://www.mcb.co.uk.html.

[2] ANDEL, T. (1996), "Carrier selection tools: Open a window to service", *Transportation and Distribution*, vol. 37, pp. 27-32, pp. 24-5.

[3] BARNEY, J. A. (1986), "Organizational culture: Ban it be a source of sustained competitive advantage?", *Academy of Management Journal*, vol. 11, no. 3, pp. 656-665.

[4] BARNEY, J. A. (1991), "Firm resources and sustained competitive advantage", *Journal of Management*, vol. 17, no. 1, pp. 99-120.

[5] BARNEY, J. A. (1997), Gaining and Sustaining Competitive Advantage, Addison Wesley Publishing Company, Inc.

[6] BENAYOUN, R. and SUSSMANN, B (1996), "ELECTRE: Une methode Pour Guider Le Choix En Presencede Points De Vue Multiples", Sema (Metra International), Dir. Sci., Note de Traveil, Paris.

[7] BENAYOUN, R. and SUSSMANN. B (1966), "ELECTRE: Une methode Pour Guider Le Choix En Presencede Points De Vue Multiples", Sema (Metra International), Dir. Sci., Note de Traveil, Paris.

[8] BRADDY, B. (2002) "New Avenues for Logistics Cost Reductions: Replacing Inventory with Information", *Inbound Logistics*, January, pp. 14-15.

[9] BRANS J. P., VINCKE, P and MARESCHAL B. (1986), "How to select and how to rank projects: The PROMETHEE method", *European Journal of Operational Research*, vol. 24, pp. 228–38.

[10] BRANS, J. P. and VINKE, P. H. (1985), "A preference ranking organization method (The PROMETHEE Method for Multiple Criteria Decision Making)", Management Science, Vol. 31, pp. 647-656.

[11] BRANS, J. P., VINKE, P. H. and MARESCHAL, B. (1984), "PROMETHEE: A new family of outranking methods in multi-criteria analysis", in J.P. Brans, ed., *Operations Research '84*, Elsevier Science Publishers, pp. 477-490.

[12] CHOPRA, S. and MEINDL, P. (2003), Supply Chain Management: Strategy, Planning and Operation, Pearson Education Asia.

[13] COYLE, J., BARDI, E. J. and J. C. LANGLEY, (2003), The Management of Business Logistics: A Supply Chain Perspective, Seventh Edition, South–Western, A division of Thomson Learning Inc.

[14] DIERICKX, I. and COOL, K. (1989), "Asset stock accumulation and sustainability of competitive advantage", *Management Science*, vol. 35, no.12, pp. 1504-1513.

[15] DRICKHAMMER, D. (2002), "Logistics and distribution: rough road ahead", http://www.iwvaluechain.com/features/articles.asp?ArticleId=1218.

[16] FACTOR, R (2001), Supply Chain Management, The Retail Advisor, Fall.

[17] FLINT, et al. (2001) "Logistics service quality as a segment-customized process", *Journal of Marketing*, vol. 65, pp 82-104.

[18] FLYNN, J. (1987), "Transportation: why pay more?", *Purchasing World*, vol. 13, pp. 50-62.

[19] GATTORNA, J. L. (1997), Strategic Supply Chain Alignment, Hampshire: Gower Publishing Limited.

[20] GRANT, R. M. (1991), "The resource-based theory of competitive advantage: Implications for strategy formulation", *California Management Review*, pp. 114-135.

[21] HANDFIELD, R B and NICHOLS, E L (1999), Introduction to Supply Chain Management, Prentice Hall, New Jersey:

[22] HARRINGTON, L.H. (1996), "Truckload transportation: The big squeeze is on", *Transportation and Distribution*, vol. 37, pp. 35-70.

[23] KAPOOR, S. K. and KANSAL, P. (2003), Basics of Distribution Management: A Logistical Approach, First edition, PHI, New Delhi.

[24] LAMBERT, D. M. and STOCK, J. R. (1993), Strategic Logistics Management, Third edition, Irwin McGraw-Hill, New York.

[25] LAMBERT, D. M. and STOCK, J. R. (2001), Strategic Logistics Management; Fourth edition, Irwin McGraw-Hill, New York.

[26] MASSAM, B and ASKEW, L. (1983), Problems of Comparing Rural Public Transport Policies in Using Saskatchewan a Concordance Analysis and Multi-Dimension Scaling Procedure, University of Toronto and York University.

[27] MCDONALD, M.E. (1993), "Tips on truckload shipping", *Traffic Management*, vol. 32, pp. 60-63.

[28] MILLIGAN, B. (1999), "Global economic rally puts heat on shippers and carriers", *Purchasing*, vol. 127, July, pp. 88-97.

[29] MILLIGAN, B. (1999). "Make transportation a visible part of the supply chain",http://www.manufacturing.net/pur/index.asp?layout=articleWebzinead article id=CA 147541.

[30] MILLIGAN, B. (2000), "Transportation and the supply chain: transportation still falls through the supply chain cracks", Available From: http://www.manufacturing.net/pur/index.asp?layout=articleWebzineandarticleid=CA139528.

[31] MOULTRIE, W. H. (1998), "Freight is no longer solely freight", *Inbound Logistics*, vol. 18, no. 2, pp. 62-78.

[32] POOLEY, J. (1992), "A vehicle-routing algorithm for the less-than-truckload vs multiple-stop truckload problem", *Journal of Business Logistics*, vol. 13, pp. 239-258.

[33] PRAHALAD, C. K. and HAMEL, G. (1990), "The core competence of the corporation", *Harvard Business Review*, pp. 79-91.

[34] ROY, B. (1968), "Classement et choix en presence de criteres multiples, Rere. 2 'Annee' ", vol.8, pp. 57- 75.

[35] ROY, B. (1971), "Problems and methods with multiple objective function", *Mathematical Programming 1*, pp. 239 - 266.

[36] ROY, B. (1990), "The outranking approach and the foundations of ELECTRE methods", Edited by C.A.Bana e Costa, Springler-Verlag, pp. 155-183.

[37] ROY, B. (1991), "The outranking approach and the foundation of ELECTRE methods", *Theory and Decision*, vol. 31, pp 49-73.

[38] ROY, B. (1996), "Multi-criteria methodology for decision aiding", Kluwer Academic Publishers.

[39] ROY, B. and VINCKE, P. (1984), "Relational systems of preference with one or more pseudo-criteria: some new concepts and results", *Management Science II*, pp. 1323-1335.

[40] ROY, B., and HUGONNARD, J. (1982), "Ranking of suburban line extension projects on Paris metro system by a multi-criteria method", *Transportation Research*, vol.16, no. 4.

[41] SCHARY, P. B and SKJOTT-LARSEN, T. (1995), Managing the Global Supply Chain. Copenhagen, Handelshojskolens Forlag.

[42] SYNDER, A. V. and EBELING, H. W. (1992), "Targeting a company's real core competencies", *Journal of business strategy*, vo.13, no. 6, pp. 26-32.

[43] TAMPOE, M. (1994), "Exploiting the core competences of your organization", *Long Range Planning*, vol. 27, no. 4, pp. 66-77.

[44] THUERMER, K. E. (1992), "Service, schedule reliability are tops", *Global Trade*, vol. 112, pp. 24-50.

[45] TURNER, D. and CRAWFORD, M. (1994), "Managing current and future competitive performance: the role of competence", Competence-based Competition, ed. Hamel, G. and Heene, A., John Wiley and Sons, New York.

[46] VINCKE, P. (1990), Basic Concept of Preference Modelling: In Reading in Multi-Criteria Decision Aid, Edited by C. Bana e. Costa, Springer

[47] WEIL, M. (1998), "Moving more for less", *Manufacturing Systems*, vol. 16, pp. 90-4.

[48] YEN, D.C. and Chou, D.C. (2000), "Wireless communications: applications and managerial issues", *Industrial Management and Data Systems*, vol. 100, no. 9, pp. 436-443.

Chapter 5

Design of Information Driver in Supply Chain Management

5.1 Introduction

In today's marketplace, organizations are looking for ways to differentiate themselves from their competitors. Creating competitive advantage is vital to sustaining growth. Companies are aggressively pursuing initiatives to better manage their supply chains. In that sense, many companies are expanding the scope of management of their operations to manage upstream and downstream channels. Investment in information technology (IT) for managing supply chains has been an effective way of obtaining competitive advantage (Spalding, 1998; Kwan, 1999). IT consists of the hardware and software throughout a supply chain that not only gathers but also analyses and acts on information. IT serves as the eyes and ears (and sometimes a portion of the brain) of management in a supply chain, capturing and analysing the information necessary to make a good decision. For instance, an IT system at a PC manufacturer may tell a manager how many Pentium chips are currently in stock, IT is also used to analyse the information and recommended an action. In this role, an IT system at a PC manufacturer could take the number of chips in inventory, look at demand forecasts, and determine whether to order more chips from Intel. Using IT systems to capture and analyse information can have a significant impact on firm's performance. For example, a majority of computer working stations and servers found that much of the information on customer demand was not being used to set production schedules and inventory levels. The manufacturing group lacked this demand information, which forced to make inventory and production decisions blindly. By installing supply chain software, the company was able to gather and analyse data to produce recommended stocking levels. Table 5.1 provides the examples of corporations that provide IT tools/services for achieving supply chain management. Table 5.2 provides examples of corporations that have utilized the services provided by corporations in table 5.1.

Table 5.1: Examples of corporations that provide IT tools/services for achieving SCM

Corporation	Direct benefits from IT related software packages in SCM
Allied-Crop.	Global company integrating SCM services to industrial clients worldwide.
CAPS Logistic Inc.	Specializing in decision optimization software for supply-chain modelling.
Chesapeake Decision Sciences, Inc.	Provides software and services for developing supply-chain planning and scheduling solutions
Cyber System Technologies, Inc.	Offers fully-automated, supply-chain management systems, called IntraMalls.
Distinction Software	Specializes in high quality Windows-based supply-chain planning software for the process manufacturing industry.
Eshbel	Offers an integrated supply-chain management solution to small and medium-size organizations.
Fygir	Inter-nation provider of SCM solutions to clients in the beverage, food, pharmaceutical, and chemical industries.
Global Information Solutions	Provides logistics/supply-chain software products and custom programs.
i2 Technologies	Provides client / server based e-BPO software products for SCM and related business process applications.
Inter Trans Logistics	Provides enterprise-wide, integrated client/server SCM

Solutions	software applications.
Logic Tools, Inc.	Develops SCM tools for intelligent strategic, operational and tactical decisions
Lyte Group, Inc.	Offers integrated SCM and planning software solutions
Supply Chain@ Solutions	Developer of application software to manage the supply-chain environments of manufactures, wholesalers and etc.
Web plan	Developers of a suite of SCM software for mid-size manufacturers that interface with virtually any ERP/MRP system.

Table 5.2: Examples of corporations that have successfully implemented IT related software packages in SCM

Corporation	Direct benefits from IT related software packages in SCM
Cardinal Logistics, Inc.	Increased customer service; reduced customer's inventory levels; reduced customer's transportation costs.
Compaq	Increased on-time delivery to 95 percent; decreased inventory; decreased order-to-receipt cycle time to five days.
Cumberland Packaging	Decreased inventory by 10 to 15 percent, or approximately by $2 million; reduced production costs substantially.
Data Card	Reduced engineering change process time from two weeks to two hours.
Kobe Copper Products	Increased the information sharing across the company dramatically. Approximate saving of $270,000 per year on account of this information sharing.

Pair Gain	Saved millions of dollars by strengthening corporation among employees and outside business partners; cut change cycle time by nine weeks.
Philips Semiconductors	Increased forecasting accuracy; decreased inventory levels; integrated logistics and marketing functions.
Thompson Consumer Electronics	Reduced planning cycle time from four to five weeks to one week; reduced raw materials, work-in-process and finished goods inventory substantially.
Xircom	Increased the speed of engineering change order cycle by five times; permitted instant broadcast of product data worldwide.

Using the IT system enabled the company to cut its inventory in half because managers could now make decisions based on information rather than educated guesses. Large impacts like this underscore the importance of IT as a driver of supply chain performance. Therefore, information is crucial to making good supply chain decisions at all three levels of decision making (strategy, planning and operations) and in each of the other supply chain drivers (inventory, transportation and facilities). IT enables not only the gathering of this data to create supply chain visibility but also the analysis of this data so that the supply chain decisions made will maximise profitability. According to Simchi-Levi *et al.* (2003), objectives of IT in SCM are: providing information availability and visibility, enabling single point of contact of data, allowing decisions based on total supply chain information and enabling collaboration with supply chain partners. The most typical role of IT in SCM is reducing the friction in transactions between supply chain partners through cost-effective information flow (Cross, 2000). On the other hand, IT is more importantly

possibilities of selecting from a larger supplier base. The classic work of Malone *et al.* (1987) proposed that the value offerings through IT are electronic communication (speed of communication), electronic brokerage (by IT providing a "lean", automated intermediary for resolving market transactions), and electronic integration (coupling of processes). IT seems to be particularly important in fast clock speed industries (Guimaraes *et al.*, 2002) or when flexibility and agility is needed (Sanders and Premus, 2002; Heinrich and Betts 2003). There is a substantial amount of research conducted that addresses the role and impact of information technologies in managing supply chains. Several research studies provide comprehensive definitions of supply chain management (SCM) from an IT perspective (Muller, 1993; Johnson, 1997). The overview articles, on the other hand, include a diverse range of topics such as the role of IT as a critical element in SCM (Scott and Westbrook, 1991; Marcia, 1994; Parker, 1994; Bradley, 1996; Copacino, 1996; Andel, 1997; Barnes, 1997; Dawe, 1997), IT and non-IT measurement issues in SCM (Ellram, 1990), different types and effective applications of IT in SCM (Szymankiewicz, 1997), the value of IT in SCM (Van, 2001; Lee and Whang, 2001; Levary, 2000; Cross, 2000 and Bowersox and Daugherty, 1995), IT roadblocks and pitfalls to implementing SCM (Ellram, 1990), and the comparisons of SCM practices among different businesses and industries (Parker, 1994; Hill, 1995). These analyses and comparisons also look at the role of IT. Several researchers have also suggested specific models and/or methodology for implementing the principles of global supply chain management (GSCM) (Stevens, 1990; Muller, 1993; Battaglia, 1994; Weil, 1997; Mason and Towill, 1998). IT is an integral component of all these models, methodologies and performance measures. There exists a fair amount of research that deals with the assessment and successful implementation of IT for GSCM by manufacturing (VanOldenborgh, 1994; Foster, networks is created. Shared IT is often used between suppliers and customers, but sometimes also involves competing organizations, research institutions, or consultancies.

5.2.1 Internal IT

The category of internal IT encompasses all information systems that are only used within organizational boundaries. These systems can support the entire organization, or specific tasks functions within the organization. Applications that are basically used inside organization are office automation, transaction processing systems, enterprise resource planning systems, data warehousing systems, groupware applications, intranets, and executive information systems. Table 5.3 illustrates the major benefits and different types of internal IT applications.

Table 5.3: Applications of internal IT and their benefits

Applications of internal IT	Benefits
Office automation	• Reduction of processing time • Improvement of quality • Reduction of time-consuming routine work
Transaction processing	• Reduction of overhead • Faster response to customer demands
Enterprise resource planning	• Business process reengineering • Reduction of cost • Improvement of customer service
Data warehousing	• Improved customer care • Better planning of future developments
Groupware	• Improved flow of information • Reduction of redundant work • Improvement of work-quality
Intranets	• Provide additional organization-intem services

	• Improved flow of information • Better customer service
Executive information	• Improved strategic planning • Executive decision-making support • Improvement of customer orientation

5.2.2 Shared IT

None of today's corporations exist as isolated entities. Companies are part of a marketplace where different types of organizations come together and exchange information, services, and goods. Shared IT relates to computer and communication technology, which supports doing business between a corporation and organizations outside its boundaries (Jonston and Vitale, 1988). These organizations can be geographically dispersed and utilize modern network technology. The shared use of IT helps to support an organization's interactions with other organizations, i.e. buyers and sellers (Applegate *et al.*, 1996). Inter-organizational systems, EDI and extranets are the most popular shared IT tools. Table 5.4 shows these applications of shared IT and the benefits to an organization engaging in these technologies.

Table 5.4: Applications of shared IT and their benefits

Applications of shared IT	Benefits
Inter-organizational systems	• Reduction of transaction costs • Increased customer responsiveness • Increase efficiency • Differentiated products and services • Increased bargaining power
Electronic data interchange	• Reduction of costs for order processing • Reduction of inventory and inventory costs • Elimination of labor-intensive tasks • Enhanced communication

Extranets	• Strengthens closeness between participating organizations • Reduction of operational costs • Enhanced communication • Reduction of cooperation costs

5.3 Development of decision support system framework for design of information driver

A decision support system framework is developed for design of information driver in SCM, which consists of four phases and it is shown in figure 5.1. Each phase is discussed below.

Phase I: (Coordination and information sharing): Coordination ensures each part of the supply chain takes actions that increase total supply chain profits and avoids actions that improve its local profits but hurt total profit. In this phase, to achieve coordination in the supply chain, there should be involvement of all members in supply chain and they should work together towards for achieving supply chain objective.

Phase II (Enabling technology): Many technologies exist that share and analyse information in the supply chain. In this phase enabling technology should be decided on the basis of technology capability, investment requirement and return on investment.

Phase III (Push or Pull): All processes in a supply chain fall into one of the two categories depending on the timing of their execution relative to end customer demand. A push/pull view in the supply chain is very useful while considering the strategic decision in the supply chain. In traditional supply chain most of the process is push process. A supply chain can not have all process to be pull. The extent of the pull or push is determined on the basis of competitive strategy, demand pattern and product value/cost.

Phase IV: (Forecasting and aggregate planning): In this phase, to achieve more accurate forecast which is significant input to aggregate plan, collaboration with supply chain partners should be created. To develop aggregate plan, one has to think beyond the enterprise to the entire supply chain to consider the internal and external constraints.

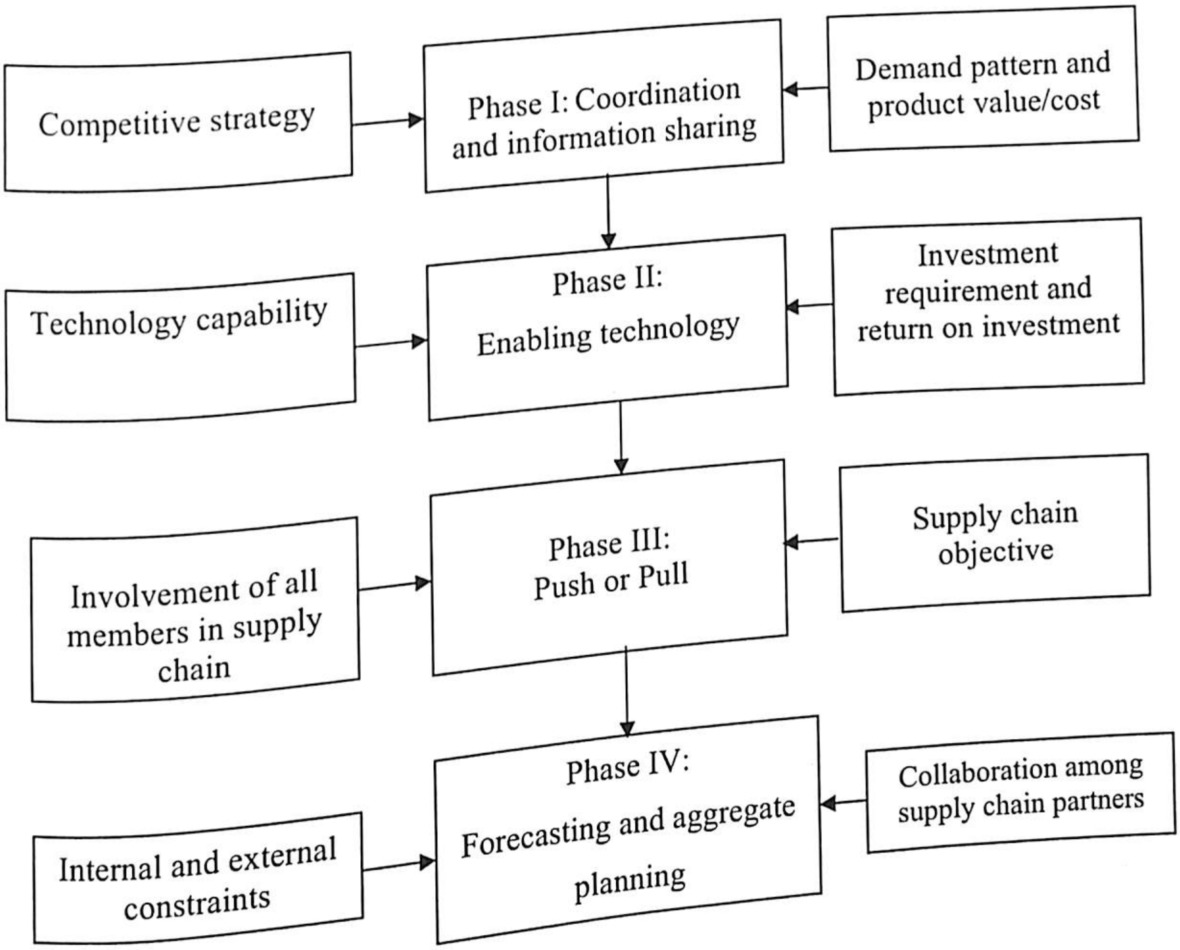


Figure 5.1: Decision support system framework for design of information driver

5.3.1 Coordination and information sharing

Several studies have been carried out regrading co-ordination aspects in supply chain management. Fayol (1949), one of the first classical management writers, listed coordination as one of the critical elements of management. He pointed to the necessity of "harmonising the separate activities and departments into a single whole". Barnard (1938) conceptualised organisations as being systems of co-operative efforts and coordinated activities. Thompson's (1967) action theory of organisation paid a great deal of attention to the different types of interdependence existing within organisations and to methods for achieving high levels of co-operation and coordination. Despite the importance co-ordination aspects bear in the networking process, in the literature they are dealt with almost exclusively with reference to single organisations. Instead, since co-ordination concerns "the combination of parts to achieve most effective or harmonious results" (Thompson, 1967), it seems much more critical when those parts belong to several organisations. Co-ordination is thus a critical element, even more so when the units involved belong to several organisations rather than to a single firm, namely, when it operates between units that remain separated at geographical, cultural, legal and organisational levels. A firm needs to develop effective coordination within and beyond its boundaries in order to maximise the potential for converting competitive advantage into profitability (Dyer and Singh, 1998). Some of the negative consequences of poor coordination include higher inventory costs, longer delivery times, higher transportation costs, higher levels of loss and damage, and lowered customer service (Lee *et al.*, 1997). Since changes that occur in any one of the chain members are likely to affect the performance of the others, coordination is useful for managing interdependent logistics activities in order to mitigate demand variability and unnecessary inventory. Therefore supply chain management is related to the co-ordination of products and information flows among suppliers, manufacturers, distributors, retailers and customers (Xiande, Jinxing and Zhang, 2002). With appropriately sharing information between suppliers and retailers and co-ordinating their replenishment and production decisions under demand uncertainty, it is possible to further reduce costs and improve customer service levels.

5.3.2 Enabling technology

Many technologies exist that share and analyse information in competitive supply chain. Managers must decide which technologies to use and how to integrate these technologies into their companies and their partner's companies. The consequences of these decisions are becoming more and more important as the capabilities of these technologies grow. Some of these technologies include EDI, ERP and SCM. Electronic data interchange (EDI) allows companies to place instantaneous, paperless purchase orders with suppliers. EDI is not only efficient, but it also decreases the time needed to get products to customers, as transactions can occur more quickly and accurately than when they are paper-based. Internet has critical advantage over EDI with respect to information sharing. The Internet conveys much more information and therefore offers much more visibility than EDI. Better visibility enables stages in the supply chain to make better decisions. Internet communication between stages in the supply chain is also easier because a standard infrastructure (the World Wide Web) already exists. Enterprise resource planning (ERP) system provides the transactional tracking and global visibility of information form any part of a company and its supply chain that allows intelligent decisions to be made. This real time information helps a supply chain to improve the quality of its operational decisions. ERP systems keep track of information, whereas the Internet provides one method with which to view this information. Supply chain management adds a higher layer to ERP systems. This software provides analytical decision support in addition to the visibility of information. ERP systems show a company what is going on, while SCM systems help a company decide what it should do.

5.3.3 Push or Pull

Supply chain is the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of ultimate customers. The supply chains can be classified into three types i.e. traditional supply chain (push process), e-supply chain (pull process) and competitive supply chain (push and pull). The three types of supply chains are discussed below.

Traditional supply chain (push): It is a serial supply chain existed until pre internet solution. All supply chain processes can be broken into following four process cycles i.e. customer order cycle, replenishment cycle, manufacturing cycle and procurement cycle. Therefore, it has five stages i.e. customer, retailer, distributor, manufacturer and supplier. The benefits of the traditional supply chain are as follows:

- Decrease inventory costs by more accurately predicting demand and scheduling production to match it
- Reduce overall production costs by streamlining the flow of goods through the production process and by improving information flow between an enterprise, its suppliers and distributors.
- Improve the customer satisfaction by offering better quality, higher product variety and fast response.

E-supply chain (pull): The latest generation of supply chain management is web centric. It is characterized by the marriage of the internet and supply chain and has resulted in the birth of e-supply chain. These internet enabled e-supply chain applications have integrated all branches of the supply chain and emerged as the most effective means of supply chain operation. E-supply chain (i.e. e-procurement, e-commerce and e-collaboration) can change the supply chain from a linear and rigid chain into a dynamic chain. E-procurement, e-commerce and e-collaboration are discussed below.

E-commerce: It refers generally to all forms of transaction involving both organizations and individuals that are based upon the electronic processing and transmission of data, including text, sound and visual images.

E-procurement: The procurement process is that process by which a manufacturer procures products from suppliers. Internet procurement solutions automate all steps of procurement process. Now, instead of only dealing with local and large parts dealers, manufacturers and suppliers have access to a competitive, global market via the internet and e-procurement applications. Many more players are brought into the supply chain, but all that they have to offer is consolidated into a single database, linked to the rest of the chain by the information hub.

E-collaboration: It is simply information sharing, collaborative planning and collaborative product development. The information hub stores quantitative information and it can also serve as a platform for information sharing between supply partners. Everything from purchase orders, sales order, invoices, checks and other business documents may be shared over the internet. Collaborative planning provides a means for implementing group decision-making and in a cost effective way, because it considers every part of the chain. Enterprises across the chain can effectively exchange all necessary knowledge to make wise decisions for the whole chain. Essentially, e-collaboration technology allows real time sharing of product sales forecasts, replenishment plans and as, result, and it can closely match supply and demand across the whole chain. Ultimately, the collaborators can jointly reduce inventory costs and customer service levels.

Some of the benefits of E-supply chain are as follows:

- Increase the speed and accuracy with which businesses can exchange information, there by reducing costs and errors in transactions.
- Help in speed notification of product design changes and adjustments.
- Electronic order tracking
- Ease in determining customer demand fluctuations
- Ease in making customer satisfaction survey
- Recording useful performance data about supply chain
- Ease in identification of new supplier
- Compare potential suppliers quickly on a wide variety of criteria such as quality, price and delivery.
- Run 24/7 (i.e. 24 hours in a day and seven days in week)

Some of the potential disadvantages of e-supply chain are as follows:

- The cost and benefit is hard to quantify.
- It requires highly educated software professionals who may be difficult to find, recruit, develop and retain.
- The cost of entry into some e-commerce reengineered supply chains may eliminate or limit small companies or limit small companies who otherwise could be very good supplier.
- Resistance to change may be high. Employees, customers and suppliers who are familiar to traditional business, may have difficulty with the required technology.

Competitive supply chain (push and pull): Over the past few years, as combination of economic, technology and market forces have compelled companies to examine and rethink this supply chain strategies. Some of these forces include the globalization of business, proliferation of product variety, increasing complexity of supply chain networks and the shortening of the product life cycles. To stay competitive, enlightened companies have strived to achieve greater coordination and collaboration among supply chain partners, in an approach called "competitive supply chain". It is the integration of traditional supply chain and e-supply chain, which offers the benefits of traditional supply chain and e-supply chain. The architecture of competitive supply chain is shown in the figure 5.2. The benefits of competitive supply chain are:

- Respond to customer requests
- Increase in on-time delivery
- Reduction in order fulfilment lead time
- Increase in customer satisfaction and relations
- Increase to handle unexpected challenges
- Reduction in inventory Low cost of purchased items
- Reduction in overall cost
- Increase in overall productivity
- Increase in overall product quality
- Ease in market penetration
- Reduction in product innovation lead-time
- Reduction in cost of new product development
- Reduction in logistics cost
- Increase in share price/ shareholder value
- Increase in revenue growth
- Increase in profitability

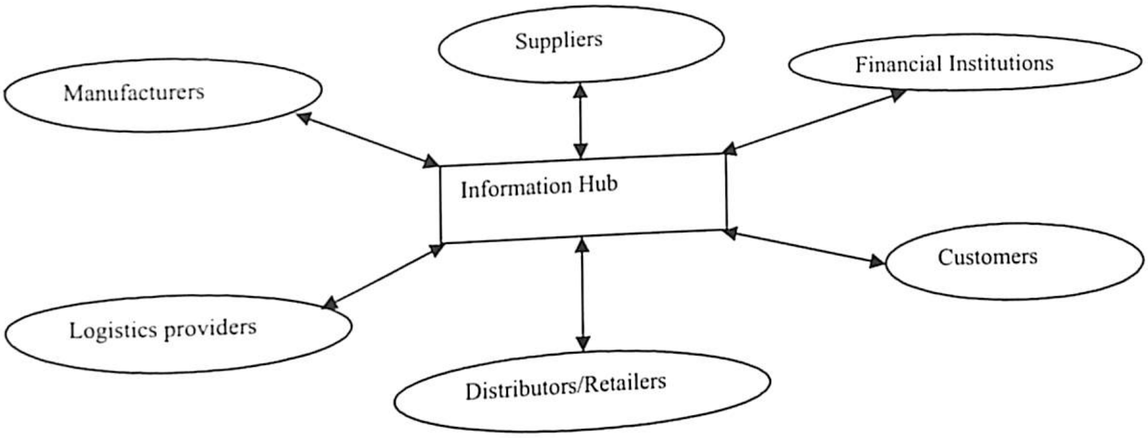


Figure 5.2: Architecture of competitive supply chain

5.3.3.1 Development of relative rating model for justification of competitive supply chain

In the modelling approach to decision making, a major problem consists in the scaling of judgement. This is, in general, the true situation in most decision-making cases involving the evaluation of non-measurable attributes. This is also the situation when the attribute performances could be measured, but no measurable definitions of them available prior to the selection process. In those cases, in order to select the best alternative, it is necessary to resort to the design of scales of judgement to weigh the rating importance of one attribute over the others. Therefore, relative rating model is developed for justification of competitive supply chain. Relative rating model enables the decision maker to represent the simultaneous interaction of many factors in complex, unstructured situation. A highly user-friendly computer model is developed which assists the user for the evaluation of his/her choices. A thorough analysis of the problem is required along with the identification of the important attributes involved. The selection of the attributes is determined through literature survey and discussions held with experts. Th e attributes and sub -attributes used in the relative rating model for justification of competitive supply chain are as follows:

Suppliers [SUP]

- Involvement in design [IND]
- Delivery and quantity commitment [DQC]
- Quality and price commitment [QPC]
- Flexible [FLX]
- Policies and regulations [PAR]
- Relationship [REP]
- Continuous improvement commitment [CIC]
- Manufacturing and management procedures/methods [MMP]
- Proximity [PRX]
- Outsourcing/subcontracting [OUS]

Manufacturers [MAR]

- Facilities/Resources [FAR]
- Flexibility [FLY]
- Innovative product planning [IPP]
- Level of automation [LOA]
- Manufacturing methods [MAM]
- Capacity [CAP]
- Management procedures [MAP]
- Mode/layout styles [MLY]
- Outsourcing [OUT]

Organizational [ORG]

- Organization levels and structure [OLS]
- Growth orientation [GRO]
- Vigilance [VIL]
- Commitment to technology [CTT]
- Acceptance of risk [ACR]
- Cross functional co-operation/co-ordination [CFC]
- Receptivity [REP]
- Slack [SLA]
- Adaptability [ADA]
- Diverse and committed workforce [DCW]

Distributors/ Retailers [DIR]

- Order processing logistics [OPL]
- Warehousing logistics [WAL]
- Transportation logistics [TRL]
- Information logistics [INL]
- Inventory logistics [IVL]
- Coordination and synchronization logistics [CSL]

Logistics providers [LOP]

- Cost efficient logistics [COE]
- Time efficient logistics [TEL]
- On time delivery logistics [ODL]
- Flexible logistics [FLL]
- Range of services [ROS]

- Reliable handling logistics [RHL]
- World wide network [WWN]
- Adoption of communications technology [ACT]
- Real-time tracking [RTT]

Customers [CUS]

- Ordering ease [ORE]
- Delivery [DEL]
- Value added services [VAS]
- Service charges [SEC]
- Customer consulting [CUC]
- Installation [INS]
- Customer training [CUT]
- Better trained service personnel [BTP]
- Maintenance and repair [MAR]
- Customer feedback [CUF]

Marketing [MKG]

- Market demand [MAD]
- Market environment [MAE]
- Market segments and targets [MST]
- Markets and buying behaviour [MBB]
- Market competitors [MRC]
- Marketing strategies [MAS]
- Type of marketing [TOM]
- Marketing programs and logistics [MPL]

- Evaluation of market activities [EMA]

Financial [FIN]

- Capital outlay [CAO]
- Sources of capital [SOC]
- Production cost [PRC]
- Infrastructure cost [INC]
- Transportation cost [TRC]
- Working capital [WOC]
- Overheads and expenses [OVE]
- Cash flow projections [CFP]

Competitive position [COP]

- Improvement in forecasting [IIF]
- Improvement in productivity [IIP]
- Improvement in quality [IIQ]
- Improvement in profit margin [IPM]
- Improvement in coordination and synchronization [ICS]
- Enhancement in customer relations [ECR]
- Reduction in inventory [RIN]
- Reduction in lead-time [RIL]
- Reduction in cost [RIC]

The alternative supply chains are: traditional supply chain, e-supply chain and competitive supply chain. These alternatives are evaluated and compared in the light of above discussed set of attributes and sub- attributes.

- Traditional supply chain [TSC]
- E-supply chain [ESC]
- Competitive supply chain [CSC]

5.3.3.1.1 Algorithm

The steps to follow in using the relative rating model:

Step 1. Define the problem and determine the objective.

Step 2. Identify the alternatives available.

Step 3. Determine the main attributes/criteria and sub-attributes/criteria in each main attribute/criterion that govern the problem.

Step 4. All sub-attributes/ criteria are said to be the lowest level nodes and all main attributes/criteria are to be the top level nodes. If a main attribute/criterion does not have sub-attributes then the main attribute/criterion becomes the lowest level node.

Step 5. Assign the weightages to main attributes/criteria according to the relative rating. A relative numerical weight is allocated directly to each attribute, such that the total sums to an agreed (normalized) value.

Step 6. Similarly assign weightages to the sub-attributes/ criteria in each main attribute/criterion. The weightages are normalized.

Step 7. Consider each attribute/criterion of the lowest level node in turn and assign a weightage (relative rating) for each alternative.

Step 8. Evaluate net weightage as follows:

If main attribute/criterion is the lowest level node, then the net weightage is the weightage of the main criterion/attribute. If sub-attribute/criteria is the lowest level node, then the net weightage is the product of weightage of the sub-attribute/criteria with the weightage of corresponding main attribute/criterion.

Step 9. Evaluate the 'Desirability Index' for each alternative as follows:

$$\text{Desirability Index for each alternative} = \frac{\sum_{\substack{\text{all lowest}\\ \text{level nodes}}} \text{Net weightage} \times \text{weightage for alternative}}{\text{Number of lowest level nodes}}$$

Step 10. Select the alternative with the highest desirability index.

5.3.3.1.2 Validation

The relative rating model is evaluated by the empirical approach. The approach is to test a representative set of selected test problems. For use in this problem, the focus is developed. In this case, it is to determine the justification of competitive supply chain. The attributes are compared with each other in a relative rating for a case situation (see table 5.5). From the analysis, it is clear that the competitive supply chain is the best option (see table 5.6 and table 5.7). Highly user-friendly software, the relative rating model is developed in VC++ language to aid the user for comparison of the attributes as well as for the alternatives and for analysing the user inputs. The reliability of the judgements supplied by the user can be estimated from the graph (figure 5.3 to 5.6) that is generated for each alternative and its corresponding deciding criteria.

Table 5.5: Case situation

Industry type	Process
Production volume	High
Company vision	Star performer and market leader
Mission	Continuous improvement of products processes and people

Table 5.6: Weightages of attributes for alternatives

A	SA	W		NW		NEW	WAL			DI		
		WA	WSA	NWA	NWSA					TSC	ESC	CSC
SUP		10		0.1								
	IND		11		0.11	0.011	10	45	45	0.11	0.495	0.495
	DQC		14		0.14	0.014	10	30	60	0.14	0.42	0.84
	QPC		12		0.12	0.012	30	20	50	0.36	0.24	0.6
	FLX		12		0.12	0.012	20	30	50	0.24	0.36	0.6
	PAR		9		0.09	0.009	10	10	80	0.09	0.09	0.72
	REP		11		0.11	0.011	20	30	50	0.22	0.33	0.55
	CIC		9		0.09	0.009	25	25	50	0.225	0.225	0.45
	MMP		8		0.08	0.008	20	30	50	0.16	0.24	0.4
	PRX		7		0.07	0.007	60	10	30	0.42	0.07	0.21
	OUS		7		0.07	0.007	10	45	45	0.07	0.315	0.315
										0.2035	0.2785	0.518
MAR		10		0.1								
	FAR		12		0.12	0.012	20	50	30	0.24	0.6	0.36
	FLY		12		0.12	0.012	10	30	60	0.12	0.36	0.72
	IPP		12		0.12	0.012	30	20	50	0.36	0.24	0.6
	LOA		15		0.15	0.015	20	50	30	0.3	0.75	0.45
	MAM		12		0.12	0.012	30	20	50	0.36	0.24	0.6
	CAP		10		0.1	0.01	10	40	50	0.1	0.4	0.5
	MAP		9		0.09	0.009	40	30	30	0.36	0.27	0.27
	MLY		8		0.08	0.008	30	30	40	0.24	0.24	0.32
	OUT		10		0.1	0.01	10	40	50	0.1	0.4	0.5
										0.242	0.389	0.424
ORG		12		0.1								
	OLS		7		0.07	0.0084	20	30	50	0.168	0.252	0.42
	GRO		10		0.1	0.012	10	30	60	0.12	0.36	0.72
	VIL		15		0.15	0.018	15	25	60	0.27	0.45	1.08
	CTT		15		0.15	0.018	20	25	55	0.36	0.45	0.99
	ACR		12		0.12	0.0144	20	30	50	0.288	0.432	0.72
	CFC		15		0.15	0.018	10	30	60	0.18	0.54	1.08
	REP		6		0.06	0.0072	10	20	70	0.072	0.144	0.504
	SLA		6		0.06	0.0072	15	35	50	0.108	0.252	0.36
	ADA		6		0.06	0.0072	20	20	60	0.144	0.144	0.432
	DCW		8		0.08	0.0096	15	25	60	0.144	0.24	0.576
										0.1854	0.3264	0.6882
DIR		8		0.1								
	OPL		20		0.2	0.016	15	25	60	0.24	0.4	0.96

	WAL		14		0.14	0.0112	10	45	45	0.112	0.504	0.504
	TRL		16		0.16	0.0128	20	20	60	0.256	0.256	0.768
	INL		16		0.16	0.0128	20	20	60	0.256	0.256	0.768
	IVL		14		0.14	0.0112	10	40	50	0.112	0.448	0.56
	CSL		20		0.2	0.016	15	35	50	0.24	0.56	0.8
										0.203	0.404	0.726
LOP		11		0.1								
	COE		14		0.14	0.0154	20	30	50	0.308	0.462	0.77
	TEL		14		0.14	0.0154	20	30	50	0.308	0.462	0.77
	ODL		9		0.09	0.0099	10	40	50	0.099	0.396	0.495
	FLL		12		0.12	0.0132	10	40	50	0.132	0.528	0.66
	ROS		9		0.09	0.0099	15	25	60	0.149	0.248	0.594
	RHL		14		0.14	0.0154	35	30	35	0.539	0.462	0.539
	WWN	23	9		0.07	0.0077	20	30	50	0.154	0.231	0.385
	ACT		7		0.07	0.0077	20	40	40	0.154	0.308	0.308
	RTT		12		0.12	0.0132	15	40	45	0.198	0.528	0.594
										0.2268	0.403	0.568
CUS		12		0.1								
	ORE		6		0.06	0.0072	25	25	50	0.18	0.18	0.36
	DEL		9		0.09	0.0108	20	20	60	0.216	0.216	0.648
	VAS		12		0.12	0.0144	15	35	50	0.216	0.504	0.72
	SEC		11		0.11	0.0132	20	35	45	0.264	0.462	0.594
	CUC		12		0.12	0.0144	10	45	45	0.144	0.648	0.648
	INS		7		0.07	0.0084	15	25	60	0.126	0.21	0.504
	CUT		7		0.07	0.0084	15	25	60	0.126	0.21	0.504
	BTP		14		0.14	0.0168	20	35	45	0.336	0.588	0.756
	MAR		12		0.12	0.0144	20	35	45	0.288	0.504	0.648
	CUF		10		0.1	0.012	20	35	45	0.24	0.42	0.54
										0.2136	0.3942	0.5922
MKG		12		0.1								
	MAD		15		0.15	0.018	15	30	55	0.27	0.54	0.99
	MAE		12		0.12	0.0144	25	35	40	0.36	0.504	0.576
	MST		14		0.14	0.0168	30	35	35	0.504	0.588	0.588
	MBB		9		0.09	0.0108	25	50	25	0.27	0.54	0.27
	MRC		8		0.08	0.0096	20	40	40	0.192	0.384	0.384
	MAS		12		0.12	0.0144	20	30	50	0.288	0.432	0.72
	TOM		7		0.07	0.0084	40	30	30	0.336	0.252	0.252
	MPL		9		0.09	0.0108	30	40	30	0.324	0.432	0.324
	EMA		14		0.14	0.0168	20	50	30	0.336	0.84	0.504
										0.32	0.501	0.512
FIN		9		0.1								
	CAO		10		0.1	0.009	30	40	30	0.27	0.36	0.27
	SOC		10		0.1	0.009	10	45	45	0.09	0.405	0.405

	PRC		15		0.15	0.0135	25	40	35	0.338	0.54	0.4725
	INC		15		0.15	0.0135	50	20	30	0.675	0.27	0.405
	TRC		16		0.16	0.0144	50	20	30	0.72	0.288	0.432
	WOC		14		0.14	0.0126	30	35	35	0.378	0.441	0.441
	OVE		10		0.1	0.009	15	40	45	0.135	0.36	0.405
	CFP		10		0.1	0.009	30	35	35	0.27	0.315	0.315
										0.3595	0.3724	0.3932
COP		16		0.2								
	IIF		7		0.07	0.0112	10	40	50	0.112	0.448	0.56
	IIP		7		0.07	0.0112	15	35	50	0.168	0.392	0.56
	IIQ		10		0.1	0.016	25	40	35	0.4	0.64	0.56
	IPM		10		0.1	0.016	40	30	30	0.64	0.48	0.48
	ICS		15		0.15	0.024	30	30	40	0.72	0.72	0.96
	ECR		15		0.15	0.024	10	40	50	0.24	0.96	1.2
	RIN		15		0.15	0.024	10	40	50	0.24	0.96	1.2
	RIL		6		0.06	0.0096	10	40	50	0.096	0.384	0.48
	RIC		15		0.15	0.024	20	35	45	0.48	0.84	1.08
										0.344	0.6471	0.7867
TOTAL										**2.2978**	**3.7156**	**5.2083**

(A: attribute; SA: Sub-attribute; W: Weightage; WA: Weightage of attribute; WSA: Weightage of sub-attribute; NW: Normalized weightage; NWA: Normalized weightage attribute; NWSA: Normalized weightage sub-attribute; NEW: Net weightage; WAL: Weightage for alternatives; DI: Desirability index)

Table 5.7: Decision index for desirability of each alternative

Traditional supply chain	TSC	2.2978
E- supply chain	ESC	3.7156
Competitive supply chain	CSC	**5.2083**

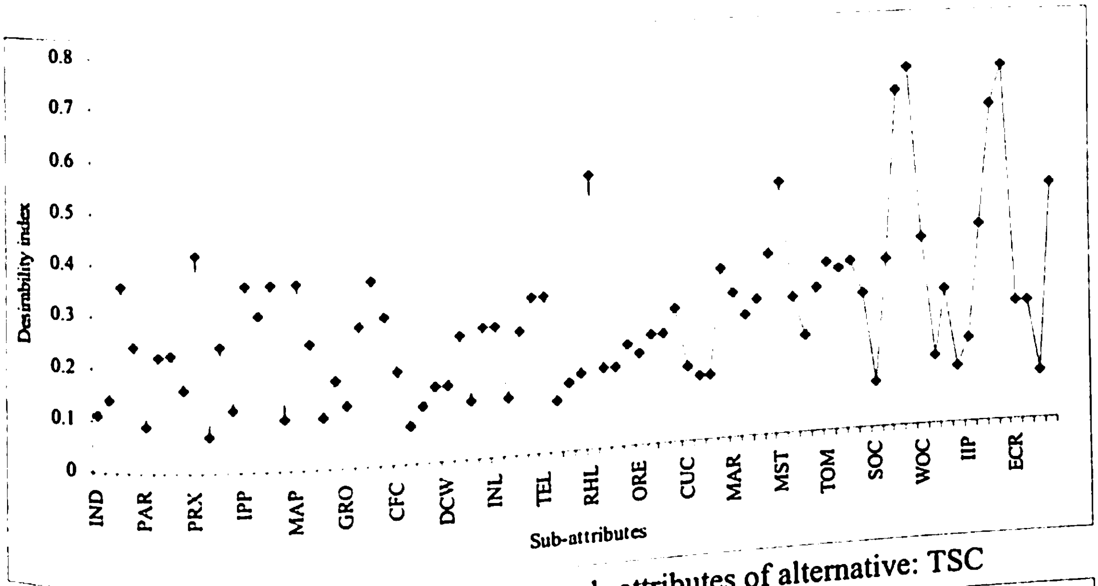


Figure 5.3: Desirability index for sub-attributes of alternative: TSC

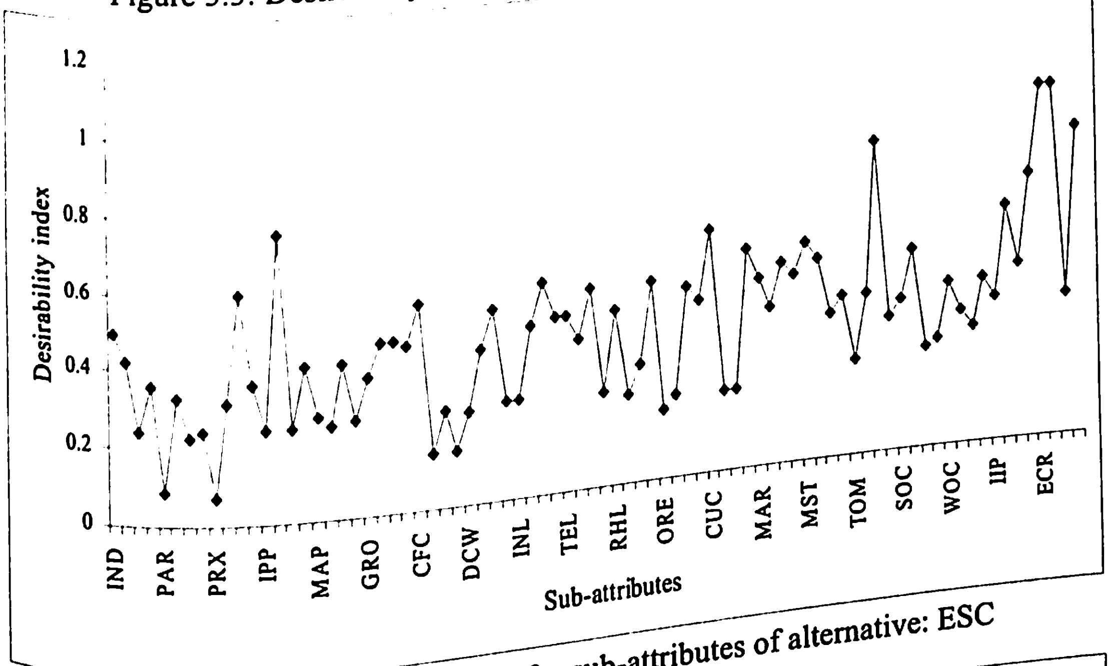


Figure 5.4: Desirability index for sub-attributes of alternative: ESC

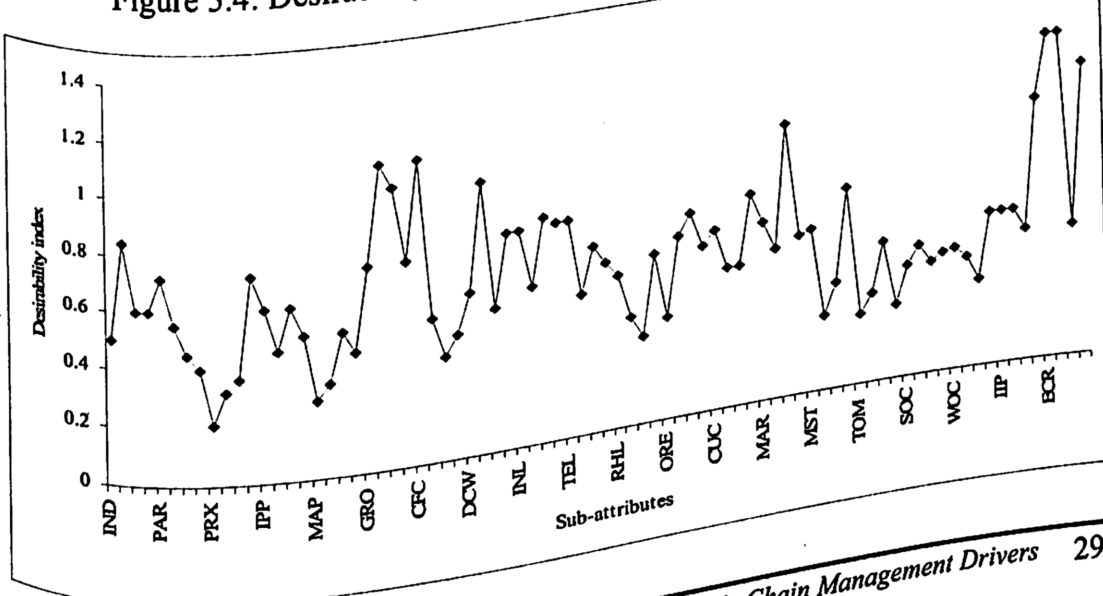


Figure 5.5: Desirability index for sub-attributes of alternative: CSC

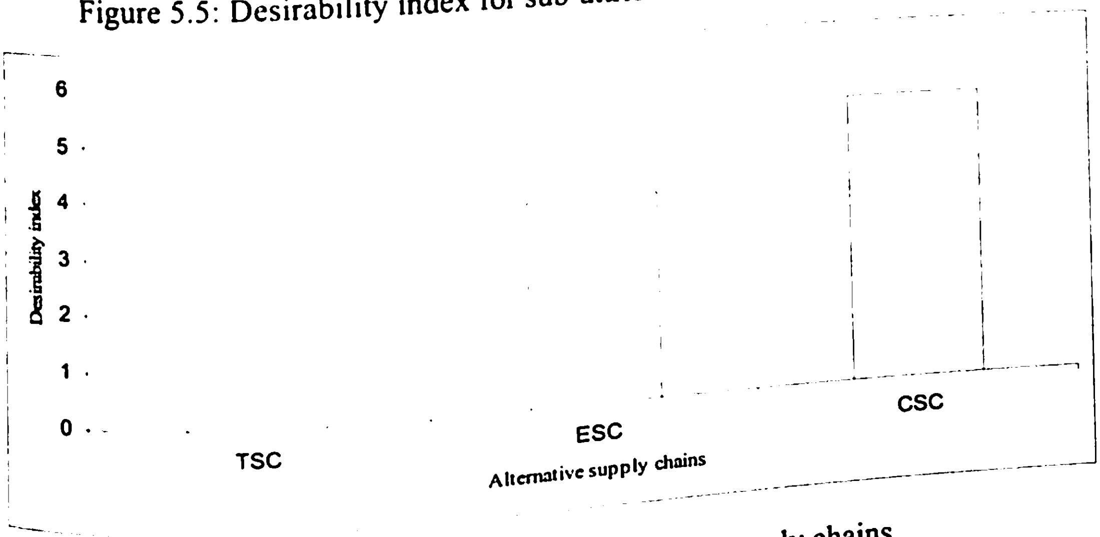


Figure 5.6: Comparison of alternative supply chains

5.3.4 Forecasting and aggregate planning

Forecasting is the art and science of making projections about what future demand and conditions will be. Mangers must decide how they will make forecasts and to what extent they will rely on them to make decisions. Companies often use forecasts both on a tactical level to schedule production and on strategic level to determine whether to build new plants or even whether to enter a new market. Then the company creates forecasts into plans of activity to satisfy the projected demand. The key decision that manager faces, is how to collaborate on aggregate planning throughout the entire supply chain. The aggregate plan becomes a critical piece of information to be shared across the supply chain because it affects both the demand on a firm's suppliers and the supply to its customers. It is obvious it can be achieved by adopting competitive supply chain.

5.4 Conclusions

With the growth of the internet, more and more companies are dedicated to e-business. Information technology application is essential for enterprises. Therefore, a decision support system framework is developed for design of information driver in

SCM. The importance of coordination and information sharing, enabling technology and push or pull in supply chain is discussed. The benefits and shortcomings of traditional supply chain, e-supply chain and competitive supply chain are highlighted. A decision support system i.e. relative rating model is developed for justification of the competitive supply chain and importance of forecasting and aggregated planning is discussed. The decision support system framework for design of information driver in SCM is validated by a case situation.

References

[1] ANDEL, T. (1997), "Information supply chain: set and get your goal'', *Transportation and Distribution*, vol. 8, no. 2, pp. 33-36.

[2] APPLEGATE, L., HOLSAPPLE, C. W., KALAKOTA, R., RADEMACHER, F. J. and WHINSTON, A. B. (1996), "Electronic commerce: building-blocks of new business opportunity", *Journal of Organization Computing and Electronic Commerce*, vol. 6, no. 1, pp. 1-10.

[3] BARNARD, C. (1938), "The Function of Executive", Harvard University Press, Cambridge.

[4] BARNES, C. R. (1997), "Lowering costs through distribution network planning'', *Industrial Management*, vol. 39, no. 5, pp. 28-31.

[5] BATTAGLIA, A. (1994), "Beyond logistics: global supply chain management'', *Chief Executive*, no. 99, pp. 48-59.

[6] BENJAMIN, R. I., ROCKART, J. F., SCOTT MORTON, M. S. and WYMAN, J. (1985), "Information technology: a strategic opportunity", *Sloan Management Review*, vol. 25, no. 3, pp. 3-10.

[7] BOWERSOX, D. J. and DAUGHERTY, P.J. (1995), "Logistics paradigms: the impact of information technology", *Journal of Business Logistics*, vol. 16, no. 1, pp. 65-80.

[8] BRADLEY, P. (1996), "1996: Meeting the supply chain's demand'', *Logistics Management*, vol. 35, no. 11, pp. 37-41.

[9] BUXMANN, P. and GEBAUER, J. (1999), "Evaluating the use of information technology in inter-organizational relationships", *Hawaii Conference on System Sciences*, Maui.

[10] COPACINO, W. (1996), "Seven supply chain principles'', *Traffic Management*, vol. 35, no. 1, p. 60-80.

[11] COTTRILL, K. (1995), "A slow reaction to supply-chain management'', *Distribution*, vol. 94, no. 13, pp. 44-58.

[12] CROSS, G. J. (2000), "How e-business is transforming supply chain management", *The Journal of Business Strategy*, vol. 21, no. 2, pp. 36-39.

[13] DAWE, R. L. (1997), "Information supply chain: building systems to meet needs'', *Transportation and Distribution*, vol. 38, no. 4, pp. 28-32.

[14] DICKEY, J. (1997), "Tightening the supply chain'', *Iron Age New Steel*, vol. 13, no. 3, pp. 74-86.

[15] ELLRAM, L. (1990), "Global supply chain management: the industrial organization perspective'', *International Journal of Physical Distribution and Logistics Management*, vol. 21, no. 1, pp. 1 -22 .

[16] FERNIE, J. (1995), "International comparison of global supply chain management in grocery retailing'', *The Service Industries Journal*, vol. 15, no. 4, pp. 134-147.

[17] FAYOL, H. (1949), "General and Industrial Management", Pitman, London.

[27] JONSTON, H. R. and VITALE, M. R. (1988), "Creating competitive advantage with inter-organizational systems", *MIS Quarterly*, vol. 12, no. 2, pp. 153-165.

[28] KEMPPAINEN, K. and VEPSÄLÄINEN, A. P. J. (2003), "Trends in industrial supply chains and networks", *International Journal of Physical Distribution and Logistics Management*, vol. 33, no. 8, pp. 70-85.

[29] KING, W. R., GROVER, V. and HUFNAGEL, E. (1989), "Using information and information technology for sustainable competitive advantage: some empirical evidence", *Information and Management*, vol. 17, pp. 87-93.

[30] KOPCZAK, L. R. (1997), "Logistics partnerships and supply chain restructuring: survey results from the US computer industry", *Production and Operations Management*, vol. 6, no. 3, pp. 226-247.

[31] KWAN, A. T. E. (1999), "The use of information technology to enhance supply chain management in the electronics and chemical industries", *Production and Inventory Management Journal*, vol. 40, no. 3, pp. 7-15.

[32] LEE, H. and WHANG, C. (1997), "Bullwhip effect in supply chains", *Sloan Management Review*, vol. 38, no. 3, pp. 93-102.

[33] LEE, H. L. and WHANG, S. (2001), "E-Business and Supply Chain Integration. Stanford Global Supply Chain Management Forum", White paper.

[34] LEE, H. L., PADMANABHAN, V. and WHANG, S. (1997), "The bullwhip effect in supply chains", *Sloan Management Review*, vol. 38, no. 3, pp. 93-102.

[35] LEVARY, R. R. (2000), "Better supply chains through information technology", *Industrial Management*, vol. 42, no. 3, pp. 24-30

[36] MALONE, T. W., YATES, J. and BENJAMIN, R. I. (1987), "Electronic markets and electronic hierarchies", *Communications of the ACM*, vol. 30, no. 6, pp. 484-497.

[37] MARCIA, M. (1994), "What's new in supply chain software?'', *Purchasing and Supply Management*, pp. 22-35.

[38] MARTIN, I. (1996), "Global supply chain management in the RAF'', *Logistics Focus*, vol. 4, no. 7, pp. 9-11.

[39] MASON, J. R. and TOWILL, D. (1998), "Time compression in the supply chain: information management is the vital ingredient", *Logistics Information Management*, vol. 11, no. 2/3, pp. 93-104.

[40] MCFARLAN, F. W. (1984), "Information technology changes the way you compete", *Harvard Business Review*, vol. 62, no. 3, pp. 98-103.

[41] MCKEE, W. (1994), "Invitation to third party", *Distribution*, vol. 93, no. 13, pp. 50-63.

[42] MULLER, E. J. (1993), "Key links in the supply chain", *Distribution*, vol. 92, no. 10, pp. 52-65.

[43] PARKER, D. W. (1994), "Logistics management: cornerstone to sustainable competitive", *Management Services*, vol. 38, no. 1, pp. 10-18.

[44] PORTER, M. E. and MILLAR, V. E. (1985), "How information gives you competitive advantage", *Harvard Business Review*, vol. 63, no. 4, pp. 149-186

[45] RYSSEL, R., RITTER, T. and Gemunden, H. G. (2004), "The impact of information technology deployment on trust, commitment and value creation in business relationships", *Journal of Business and Industrial Marketing*, vol. 19, no. 3, pp. 197-207

[46] SANDERS, N. R. and PREMUS, R. (2002), "IT applications in supply chain organizations: a link between competitive priorities and organizational benefits", *Journal of Business Logistics*, vol.23, no. 1, pp. 65-83

[47] SCOTT, C. and WESTBROOK, R. (1991), '"New strategic tools for global supply chain management'', *International Journal of Physical and Logistics Management*, vol. 21, no. 1, pp. 23-33.

[48] SIMCHI-LEVI, D., KAMINSKY, P. and SIMCHI-LEVI, E. (2003), Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies, McGraw-Hill, New York.

[49] SPALDING, J. O. (1998), "Transportation industry takes the right-of-way in the supply chain", *IIE Solutions*, vol. 30, no. 7, pp. 24-48.

[50] STEVENS, G. (1990), "Successful global supply chain management'', Management Decision, vol. 28, no. 8, pp. 25-30.

[51] STROEKEN, J. (2000), "Information technology, innovation, and supply chain structure'', *Journal International de la Gestion Techlogique*, vol. 20, no. 1/2, pp. 156-175.

[52] STUMP, R. L. and SRIRAM, V. (1997), "Employing information technology in purchasing: buyer-supplier relationships size of the supplier base", *Industrial Marketing Management*, vol. 26, pp. 127-138.

[53] SWAMINATHAN, J. M. and TAYUR, S. R. (2003), "Models for supply chains in e-business", *Management Science*, vol. 49, no. 10, pp. 1387-1440.

[54] SZYMANKIEWICZ, J. (1997), "Efficient customer response, supply-chain management for the new millennium?'', *Logistics Focus*, vol. 5, no. 9, pp. 16-22.

[55] THOMPSON, J. (1967), Organizations in Action, McGraw-Hill, New York.

[56] VAN H. R. (2001), "E-supply chains-virtually non-existing", *Supply Chain Management: An International Journal*, vol. 6, no. 1, pp. 21-28

[57] VANOLDENBORGH, M. (1994), "Distribution superhighway", *International Business*, vol. 7, no. 6, pp. 80-94.

[58] WEIL, M. (1997), "Solutions help small to medium-sized manufacturers benefit from enterprise applications", *Manufacturing Systems*, pp. 1-6.

[59] WILLIAMS, L. R., ESPER, T. L. and OZMENT, J. (2002), "The electronic supply chain", *International Journal of Physical Distribution and Logistics Management*, vol. 32, no. 8, pp. 703-719.

[60] XIANDE, Z., JINXING, X. and ZHANG, W. J. (2002), "The impact of information sharing and ordering co-ordination on supply chain performance", *Supply Chain Management: An International Journal*, vol. 7 no. 1, pp. 24- 40.

Chapter 6

Design of Inventory Driver in Supply Chain Management

6.1 Introduction

Over the past decade, there has been an increasing emphasis on SCM as a vehicle through which firms can achieve competitive advantage (Jeffrey *et al.*, 1998). SCM is a set of approaches to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements (David *et al.*, 2000). So the supply chain consists of various members or stages. A supply chain is a dynamic, stochastic, and complex system that might involve hundreds of participants. It can be defined as a network of suppliers, manufacturers, distributors and retailers, who are collectively concerned with the conversion of raw materials into goods that can be delivered to the ultimate customer. There are three kinds of flow in any supply chain: material flow, information flow, and cash flow. The material flows in the downward directions and cash flows in upward direction of the supply chain whereas the information flows in both the directions and inventory exists at all stages of the supply chain. The primary purpose of these inventories is to buffer against uncertainty arising from demand, process (Strader *et al.*, 1998) and supply. Inventory in the supply chain increases the product availability and reduces the cost by exploiting any economies of scale that may exist during both production and distribution. Inventory is major source of cost and it has a huge impact on customer responsiveness. Since, the development of the economic order quantity (EOQ) formula by Harris (1913), researchers and practitioners have been actively concerned with the analysis and modeling of inventory systems under different operating parameters and modeling assumptions. Clark and Scarf (1960) discussed about the problem of determining optimal purchasing quantities for multi-echelon inventory models. Robinson, Gao and Muggenborg (1993) developed an optimization based decision support system for designing two-echelon, multi-product distribution systems and the optimization procedure gave management the analytical support it needed to eliminate uncertainties and develop guidelines for change. Both Lee and Billington (1993) formulated and solve a nonlinear optimization problem that minimizes only the supply chain's inventory costs subject to user-specified customer service level requirements. Glassman and Tayur (1995) discussed about the effective management of inventories in large-scale production and distribution systems and did sensitivity analysis for estimating base stock levels for multi-echelon production inventory systems. Stenger (1996) presented a method to help a firm to identify the relative impact of various determinants of inventories as a means of setting priorities for inventory reduction. Moinzadeh and Aggarwal (1997) discussed about multi-echelon inventory system where all the stocking locations have the option to replenish their inventory through either a normal or a more expensive emergency resupply channel. Chen and Song (1997) considered a multi-stage serial system for which the demand distribution in each period depends upon the state of a Markov chain. They assume linear holding and backorder costs, and show that a state-dependent echelon base-stock policy is optimal for each stage. Viswanathan and Mathur (1997) proposed heuristic to determine replenishment policies for a central warehouse and many retailers that stock a number of different products to minimize long-run inventory and transportation costs. Graves *et al.* (1998) developed a model for requirements planning of multi-stage production inventory systems. The multi-level inventory models and methods are used in supply chain management as these multi-level techniques may reduce the total cost of the system substantially. It is very difficult to determine an optimal control policy for a multi-level inventory system due to the fact that such a policy depends on the structure of the system and should be based on the states of the whole system. Moreover, even if such a policy can be identified, it usually has a very complex structure and is not suitable for implementation. Therefore it is reasonable to consider simple, cost effective heuristic policies, which can be easily implemented in practice (Silver *et al.*, 1998). Ganeshan (1999) presented a near-optimal (s,Q)-type inventory policy for a production/distribution network with multiple suppliers replenishing a central warehouse, which in turn distributes to a large number of retailers. The model is a synthesis of three components: the inventory analysis at the retailers, the demand process at the warehouse, and the inventory analysis at the warehouse. The key contribution of the model is the seamless integration of the three components to analyze simple supply chains. The decisions in the model were made through a comprehensive distribution-based cost framework that includes the inventory, transportation, and transit components of the supply chain.

In today's environment, every supply chain wants not only to minimize the system wide cost but also to keep minimum inventory along the supply chain while maximizing service level requirements of the customer. This is because of the new innovative technology has made the product life cycle become short and increased the demand variability. The excess inventory in the supply chain will block the cash flow and indeed gives an adversely effect on the enterprise. The supply chain managers are thinking about including increasingly more of the supply channel in their planning processes, inventories that span more than one channel echelon becomes a focus. Rather than planning inventories at each location separately, planning their levels in concert can lead to lower overall inventory quantities. Multi-echelon inventory planning has been a particularly difficult problem to solve, but not much progress is being made in methods useful to managers (Ballou, 2004). In the following section, a mathematical formulation is developed for supply chain inventory planning (i.e. determine ordering/production quantity and service level for each member) of a serial supply chain consists of a retailer, a warehouse and a manufacturer to minimize the total system wide cost i.e. supply chain inventory capital, supply chain ordering/set-up cost and supply chain inventory stock out cost.

6.2 Development of mathematical model for supply chain inventory planning

While formulating inventory policy in the distribution system of the supply chain, the two main objectives are:

- Maintaining the specified service level to the customer, i.e. availability of stocks at the right time at the right place.
- Reducing the inventory levels in the supply chain to minimize the investment in inventory.

It is obvious that these two objectives are mutually contradictory in nature. Availability of stocks at the right place at right time requires that more stocks be kept to avoid a loss of sale, which means higher inventory carrying costs. It is therefore necessary to optimize the dispatches and production such that both objectives are satisfactorily met. A serial supply chain is one in which the companies are arranged in a series. The purpose of model is to provide a optimal reorder point, order quantity/production quantity and service level for a serial supply chain which consists of a retailer, a warehouse and a manufacturer that each member should produce/maintain to minimize the total system wide cost and maximizing the service level subject to supply chain inventory constraints. The total cost in this study include ordering cost, set up cost, inventory holding cost and stock out cost.

The assumptions are:

- The model assumes a three-echelon inventory for single product, which consists of single-manufacturer, single warehouse and single retailer.
- The model assumes that a single product, with a constant unit price at different points flows from manufacturer to distribution center and then to retailer shop from where the customer purchases the product.
- A continuous review policy (Q, r) is used to keep track of inventory at each stage at all times.
- The mean rate of demand is assumed to be constant. This assumes that the processes generating the demand remain unchanged over a considerable length of time. After that the rate of demand changes very rapidly (like technology advancement, phasing in a product, phasing out a product, fashion trends etc.). The model assumes a normally distributed demand over a period of time.
- The safety stock level of each company is a positive quantity.
- The lead-time is constant.
- Manufacturing organization is going for batch production.

Notations: The following notations are used to the model.

D = Excepted demand during a period; units/period.

H_1 – Holding cost per unit at the manufacture,

H_2 – Holding cost per unit at the warehouse

H_3 – Holding cost per unit at the retailer

C_1 – Set up cost per manufacture cycle at the manufacturing plant

C_2 – Ordering cost of warehouse per order cycle

C_3 – Ordering cost of retailer per order cycle

O_1 – Stock out cost per unit at manufacture

O_2 – Stock out cost per unit at warehouse

O_3 – Stock out cost per unit at retailer

L_1 – Demand during lead-time at manufacturer, units

L_2 – Demand during lead-time at warehouse, units

L_3 – Demand during lead-time at the retailer, units

Q_1 – Production quantity at the manufacturer per order cycle, units.

Q_2 – Order Quantity at the warehouse per order cycle, units

Q_3 - Order Quantity at retailer per order cycle, units

σ_1 - Standard deviation of demand during lead-time at manufacturer, units

σ_2 - Standard deviation of demand during lead-time at warehouse, units

σ_3 - Standard deviation of demand during lead-time at the retailer, units

k_1 – Safety factor at the manufacturer

k_2 – Safety factor at the warehouse

k_3 – Safety factor at the retailer

The details of mathematical formulation of the model are given below.

Supply Chain Inventory Capital: At the time of the arrival of an order, the expected inventory level at any member is equal to the safety stock, (S_i). After the order arrives, the inventory level raises to $Q_i + S_i$. Since the mean rate of demand is constant, the cycle inventory will linearly vary between S_i to $Q_i + S_i$. Therefore average inventory is given as: $\frac{1}{2}(Q_i + S_i) + \frac{1}{2}(S_i) = \frac{1}{2}Q_i + S_i = \frac{1}{2}Q_i + k_i\sigma_i$

The inventory capital due to one member is calculated as: $(\frac{1}{2}Q_i + k_i\sigma_i)H_i$

So the supply chain inventory capital is the sum of the expected inventory capital at each stage. It can be found out as: SCIC = $\sum_{i=1}^{3}\left(\frac{Q_i}{2} + k_i\sigma_i\right)H_i$

Supply chain ordering cost: The expected number of orders for any member is the expected demand to the order quantity. It can be found out as: Expected number of orders = $(\frac{D}{Q_i})$. So the expected ordering cost = $(\frac{D}{Q_i})C_i$. The supply chain ordering cost is the sum of the ordering cost at each stage of the supply chain (SCOC=$\sum_{i=1}^{i=3}\frac{D}{Q_i}C_i$).

Customer service: It is measured by calculating the risk of having stock out. One of the variables that the decision maker has to decide is the safety factor, k_i. We have assumed that the lead-time demand for each member is normally distributed with mean L_i. Given that the standard normal distribution is $f(x)$, and then customer service level is: $\int_{k_i}^{\infty} f(x)dx$.

Supply Chain stock out cost: The stock out rate at each member is calculated as

$$1-\int_{k_i}^{\infty} f(x)dx = 1-\int_{-\infty}^{0} f(x)dx - \int_{0}^{k_i} f(x)dx$$

$$= 0.5 - \int_0^{k_i} f(x)dx = 0.5 - \int_0^{k_i} e^{\frac{-x^2}{2}} dx = 0.5 - \sum_{n=0}^{n=\infty} \frac{(-1)^n}{n!} \frac{1}{2^n} \frac{k_i^{2n+1}}{2n+1}$$

$$= 0.5 - \frac{1}{\sqrt{2\pi}} \left(k_i - \frac{k_i^3}{6} + \frac{k_i^5}{40} - \frac{k_i^7}{336} + \frac{k_i^9}{3456} - \frac{k_i^{11}}{42,240} \right) \text{ (Considering first five terms)}$$

So the stock out cost at any member:

$$\left[0.5 - \frac{1}{\sqrt{2\pi}} \left(k_i - \frac{k_i^3}{6} + \frac{k_i^5}{40} - \frac{k_i^7}{336} + \frac{k_i^9}{3456} - \frac{k_i^{11}}{42,240} \right) \right] O_i L_i$$

The supply chain stock out cost (SCSC) is the sum of the expected stock out cost at each stage. It can be calculated as:

$$SCSC = \sum_{i=1}^{3} \left[0.5 - \frac{1}{\sqrt{2\pi}} \left(k_i - \frac{k_i^3}{6} + \frac{k_i^5}{40} - \frac{k_i^7}{336} + \frac{k_i^9}{3456} - \frac{k_i^{11}}{42,240} \right) \right] O_i L_i$$

Objective function: It consists of supply chain inventory capital, supply chain ordering cost and supply chain stock out cost, which has to be minimized.

$$\sum_{i=1}^{i=3} \left(\frac{Q_i}{2} + k_i \sigma_i \right) H_i + \sum_{i=1}^{i=3} \left(\frac{D}{Q_i} \right) C_i + \sum_{i=1}^{i=3} \left[0.5 - \frac{1}{\sqrt{2\pi}} \left(k_i - \frac{k_i^3}{6} + \frac{k_i^5}{40} - \frac{k_i^7}{336} + \frac{k_i^9}{3456} - \frac{k_i^{11}}{42,240} \right) \right] O_i L_i$$

Constraints: The manufacturing organization wants the total average inventory along the supply chain of finished product should not be greater than a particular value at any instant of time. The average inventory at each stage of the supply chain can be calculated as $(\frac{Q_i}{2} + k_i \sigma_i)$. So the total average inventory along the supply chain due to all the three members is: $\sum_{i=1}^{i=3} \frac{Q_i}{2} + k_i \sigma_i \leq x$ (Where x is the maximum average that is permissible along the supply chain). For this model, we have considered the safety factor should be within 0 to 3. So it can be written as $0 \leq k_i \leq 3$. The higher the value of k_i, the more safety stock is maintained.

6.2.1 Development of supply chain inventory planning by using optimization tool of MATLAB 6.1

MATLAB is a high performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notations. Typical uses include:

- Mathematics and computation
- Algorithm development
- Modeling, simulation and prototyping
- Data analysis, exploration and visualization
- Scientific and engineering graphics
- Application development including Graphical User Interface building

MATLAB 6.1 is an interactive system whose basic data element is an array that does not require dimensioning. This allows for solving many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time. The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects, which together represent the state-of-the-art in software for matrix computation. MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high productivity research, development, and analysis. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include: signal processing, control systems, optimization, neural networks, fuzzy logic, wavelets, simulation, and many others.

The above problem i.e. supply chain inventory planning is solved by optimization tool (MATLAB).

6.2.1.1 Results and discussion

Optimization tool (MATLAB 6.1) is applied to solve the problem . To illustrate the above model, the input parameters given in table 6.1 are considered. The supply chain inventory not more than 1500 at any instant of time for the given input (see table 6.1), the manufacturer production quantity, distributor order quantity to manufacturer and retailer order quantity to distributor are calculated as 878, 579.6 and 367.4 respectively while minimizing the total system wide cost. The service levels at different stages are also calculated as 1.3, 1.376 and 1.7619 respectively. Once the service levels are found out, then the safety stocks (multiplying service level with standard deviation during lead time) and reorder points (adding safety inventory with demand during lead time) can be calculated (see table 6.2). For maximum average supply chain inventory less than equal to 1500, 1,000 and 800, the order/production quantity, safety stock and reorder point for each member are calculated and it is shown in table 6.2, table 6.3 and table 6.4.

Table 6.1: Input parameters

	Retailer	Warehouse	Manufacturer
Holding cost/unit	$80	$75	$70
Setup cost/Ordering cost/unit	$300	$700	$1500
Stock out cost/unit	$320	$300	$280
Mean demand during lead-time	60	100	160
Standard deviation of demand during lead-time (unit)	40	45	50
Excepted demand during a period (units)			

Table 6.2: Results obtained by using optimization tool (MATLAB 6.1) for maximum average SC inventory ≤ 1500

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	367.4	579.6	878
Safety factor (service level)	1.3	1.376	1.7619
Safety stock (units)	52	62	88
Reorder point (units)	112	162	248
Total system wide cost	$155,860		

Table 6.3: Results obtained by using optimization tool (MATLAB 6.1) for maximum average SC inventory ≤ 1000

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	330	518	779
Safety factor (service level)	1.142	1.29	1.65
Safety stock (units)	46	75	83
Reorder point (units)	106	175	243
Total system wide cost	$156,890		

Table 6.4: Results obtained by optimization tool (MATLAB 6.1) for maximum average SC inventory ≤ 800

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	269	419	624
Safety factor (service level)	0.7094	1.05	1.37
Safety stock (units)	28	47	101
Reorder point (units)	88	147	261
Total system wide cost	$165260		

6.2.2 Development of differential evolution algorithm for supply chain inventory planning

Differential evolution (DE) algorithm is an improved version of genetic algorithm (GA) (Deb, 1996). DE has been successfully applied in various fields. The various applications of DE are: digital filter design (Storn, 1995), batch fermentation process (Chiou and Wang, 1999 and Wang and Cheng, 1999), dynamic optimization of continuous polymer reactor (Lee, Han and Chang, 1999), optimization of heat exchangers (Babu and Munawar, 2000), optimization of non- linear functions (Babu and Angira, 2001), fuzzy decision making problems of fuel ethanol production (Wang, Jing and Tsao, 1998), multi sensor fusion (Joshi and Sanderson, 1999) and etc. Unlike simple GA that uses binary coding for representing problem parameters, DE uses real coding of floating point numbers. The advantages of DE are its simple structure, ease of use, speed and robustness. Price and Storn (1997) gave the working principle of DE. The key parameters to be adopted for a problem are to be determined by trial and error. The key parameters of control are: NP- the population size, CR- the crossover constant, F- the weight applied to random differential (scaling factor). The detailed DE algorithm used in the present study is given below.

- Choose a strategy.
- Initialize the value of D, NP, CR, F and maximum number of generation.
- Initialize all the vector population randomly in the given upper and lower limit.
- Evaluate the cost of each vector.
- Find out the vector with lowest cost.
- Repeat
- Perform mutation, crossover, selection and evaluation of the objective function for a specified number of generations.
- For each vector x_i (target vector), select three distinct vectors x_a, x_b and x_c randomly from a current population other than vector x_i.
- Perform crossover for each target vector with its noisy vector to create a trial vector.

- Perform selection for each target vector, x, by comparing its cost with that of the trial vector. Vector with lower cost is selected for next generation.
- Till termination criteria do not meet
- Print the results

The crucial idea behind DE is a scheme for generating trial vectors. Basically, DE adds the weighted difference between two population vectors to a third vector. The flow chart of DE is given in the figure 6.1.

6.2.2.1 Results and discussion

DE algorithm has been applied to solve the problem . To illustrate the above model, the input parameter given in table 6.1 is considered. The population size, the crossover constant, the scaling factor and maximum number of generations were set to 60, 0.5, 0.8 and 2000 respectively. The supply chain inventory not more than 1500 at any instant of time for the given input (see table 6.1), the manufacturer production quantity, distributor order quantity to manufacturer and retailer order quantity to distributor are calculated as 878, 580 and 367 respectively while minimizing the total system wide cost. The service levels at different stages are also calculated as 1.216, 1.58 and 1.81 respectively (see table 6.17). Once the service levels are found out, then the safety stocks (multiplying service level with standard deviation during lead time) and reorder points (adding safety inventory with demand during lead time) can be calculated. For maximum average supply chain inventory less than equal to 1,500, 1,000 and 800, the order/production quantity, safety stock and reorder point for each member are calculated and it is shown in table 6.17, table 6.11 and table 6.8.

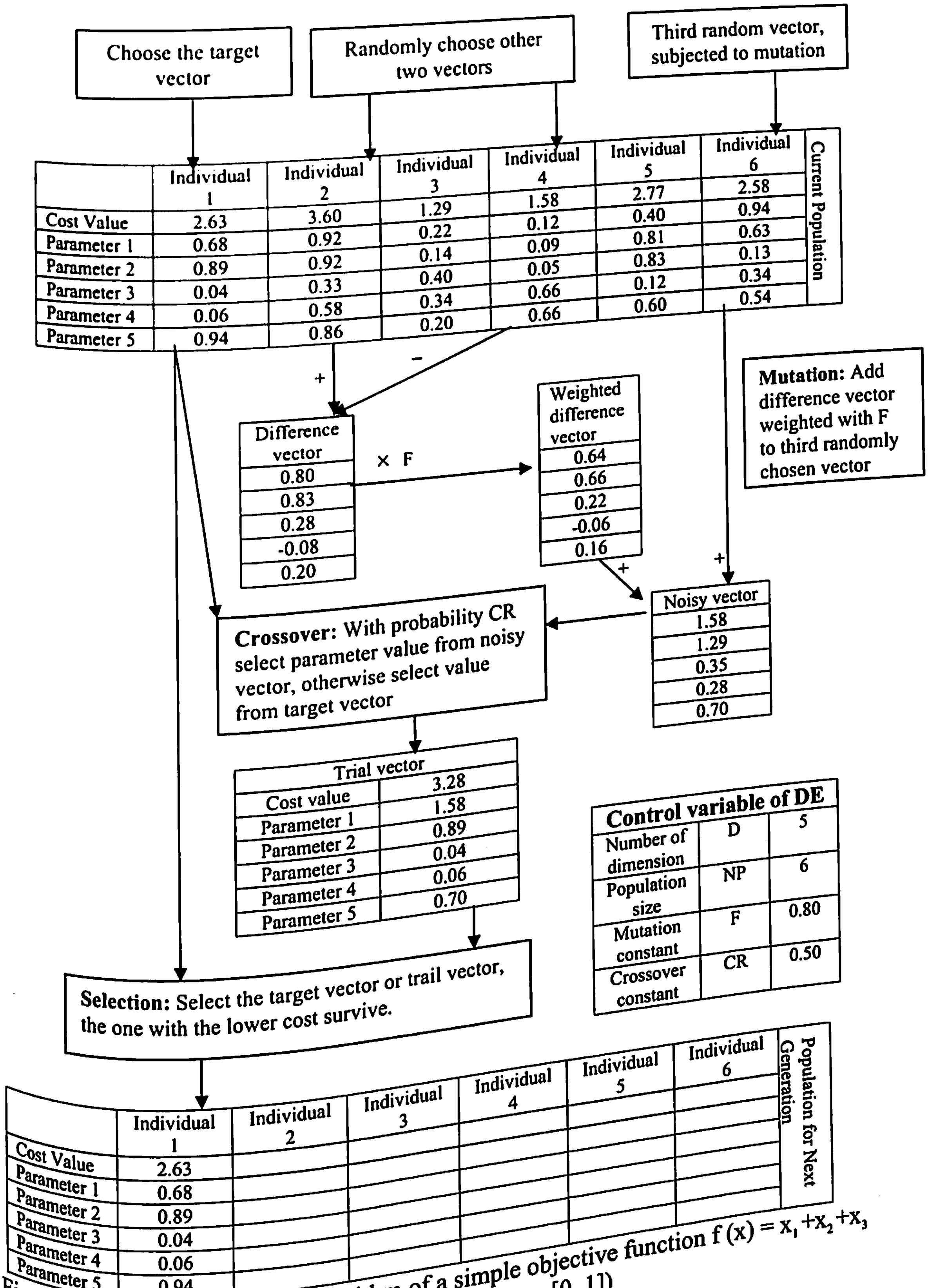


Figure 6.1: Flow chart of DE algorithm of a simple objective function $f(x) = x_1 + x_2 + x_3 + x_4 + x_5$ (variables bounded within the range [0, 1])

It is found that the results obtained by DE are better than optimization tool (MATLAB 6.1). The results are shown in table 6.18. Therefore, for maximum average supply chain inventory less than equal to 700, 750, 800, 850, 900, 950, 1000, 1050, 1100, 1150, 1200, 1250, and 1500, the order/production quantity, safety stock and reorder point for each member are calculated and it is shown in table 6.5, table 6.6, table 6.7, table 6.8, table 6.9, table 6.10, table 6.11, table 6.12, table 6.13, table 6.14, table 6.15, table 6.16 and table 6.17. The relationship between maximum average inventory and total cost in the supply chain is shown in the figure 6.2. It is found when maximum average inventory along the supply chain increases, the cost decreases and then remains constant as optimum average inventory less than maximum average inventory. The safety factor at different members in supply chain for different maximum average inventory is shown in figure 6.3. It is found that the safety factor which is indicator of service level increases along the different members in the supply chain as maximum average inventory increases and then remains constant as optimum average inventory less than maximum average inventory. As maximum average inventory increases significantly, there is no increase in safety factor indicates that there exists an optimum level of inventory that should be maintained along the supply chain to maximize service level and minimize the total cost. In this case optimum average inventory along the supply chain is 1150.

Table 6.5: Results obtained by using DE for maximum average SC inventory ≤ 700

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	258	399	594
Safety factor (service level)	0.216	1.02	1.4
Safety stock (units)	9	46	70
Reorder point (units)	69	146	230
Total system wide cost	$168781		

Table 6.6: Results obtained by using DE for maximum average SC inventory ≤ 750

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	269	419	626
Safety factor (service level)	0.481208	1.115802	1.469497
Safety stock (units)	19	50	74
Reorder point (units)	79	150	234
Total system wide cost	$164990		

Table 6.7: Results obtained by using DE for maximum average SC inventory ≤ 800

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	245	380	562
Safety factor (service level)	0.0009	0.91	1.32
Safety stock (units)	0	41	66
Reorder point (units)	60	141	226
Total system wide cost	$173317.064278		

Table 6.8: Results obtained by using DE for maximum average SC inventory ≤ 850

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	284	442	660
Safety factor (service level)	0.67	1.2	1.5
Safety stock (units)	27	50	75
Reorder point (units)	87	150	235
Total system wide cost	$161930		

Table 6.9: Results obtained by using DE for maximum average SC inventory ≤ 900

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	314	465	696
Safety factor (service level)	0.81	1.284	1.60
Safety stock (units)	32.5	54	80
Reorder point (units)	92.5	154	240
Total system wide cost	$159548		

Table 6.10 Results obtained by using DE for maximum average SC inventory ≤ 950

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	314	489	735
Safety factor (service level)	0.92	1.364	1.66
Safety stock (units)	39	58.5	83
Reorder point (units)	99	158.5	243
Total system wide cost	157769		

Table 6.11: Results obtained by using DE for maximum average SC inventory ≤ 1000

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	329	515	775
Safety factor (service level)	1.017	1.43	1.71
Safety stock (units)	41	64	86
Reorder point (units)	101	164	246
Total system wide cost	$156526		

Table 6.12: Results obtained by using DE for maximum average SC inventory ≤ 1050

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	344	541	816
Safety factor (service level)	1.1	1.5	1.76
Safety stock (units)	45	67.5	88
Reorder point (units)	105	167.5	248
Total system wide cost	155754		

Table 6.13: Results obtained by using DE for maximum average SC inventory ≤ 1100

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	360	567	858
Safety factor (service level)	1.2	1.56	1.8
Safety stock (units)	48	70	88
Reorder point (units)	108	170	248
Total system wide cost	155398		

Table 6.14: Results obtained by using DE for maximum average SC inventory ≤ 1150

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	367	580	878
Safety factor (service level)	1.216	1.58	1.81
Safety stock (units)	48.6	71	90.5
Reorder point (units)	108	171	250.5
Total system wide cost	$155360		

Table 6.15: Results obtained by using DE for maximum average SC inventory ≤ 1200

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	367	580	878
Safety factor (service level)	1.216	1.58	1.81
Safety stock (units)	48.6	71	90.5
Reorder point (units)	108	171	250.5
Total system wide cost	$155360		

Table 6.16: Results obtained by using DE for maximum average SC inventory ≤ 1250

	Retailer	Warehouse	Manufacturer
Order/Production quantity (units)	367	580	878
Safety factor (service level)	1.216	1.58	1.81
Safety stock (units)	48.6	71	90.5
Reorder point (units)	108	171	250.5
Total system wide cost	$155360		

Table 6.17: Results obtained by using DE for maximum average SC inventory ≤ 1500

	Retailer	Warehouse	Manufacturer
Order quantity (units)	367	580	878
Safety factor (service level)	1.216	1.58	1.81
Safety stock (units)	48.6	71	90.5
Reorder point (units)	108	171	250.5
Total system wide cost	$155360		

Table 6.18: Comparison of the results obtained by using DE and optimization tool (MATLAB 6.1)

	Total system wide cost using DE	Total system wide cost using optimization tool (MATLAB 6.1)	Remarks
Maximum average SC inventory ≤ 1500	$155,360	$155,860	The result obtained by using DE is better.
Maximum average SC inventory ≤ 1000	$156,525.5	$156,890	The result obtained by using DE is better.
Maximum average SC inventory ≤ 800	$164990	$165260	The result obtained by using DE is better.

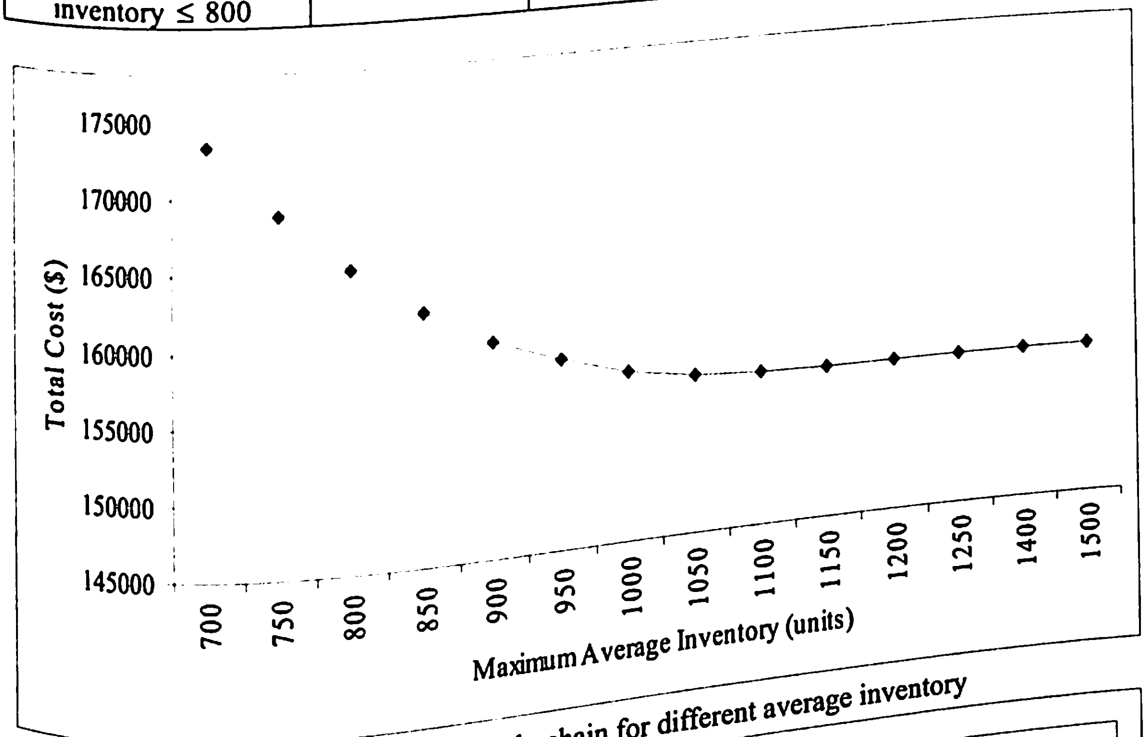


Figure 6.2: Total cost in supply chain for different average inventory

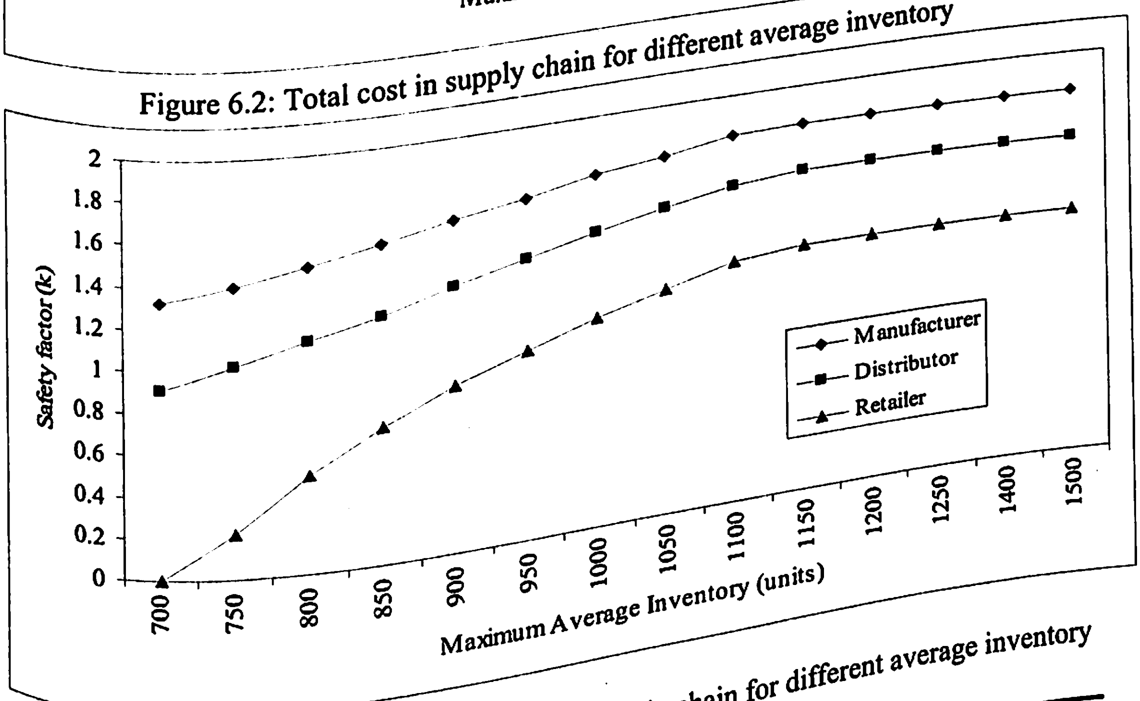


Figure 6.3: Safety factor at different members in supply chain for different average inventory

6.3 Development of simulation model for supply chain inventory planning

Simulation is one of the most popular of all quantitative techniques because it can be applied to operational problems that are difficult to model and solve analytically. Complex systems should be studied via simulation whether or not they can be analysed analytically, because it provides an easy vehicle for experimenting on the system. A large majority of major corporations use simulation in such functional areas as production, planning, engineering, financial analysis, research and development, information systems and personnel. Much of the power of mathematical models comes from distilling complex relationships down into relatively simple mathematical forms. For the systems of known relationships that can be captured in equations, mathematical models are usually the best way to go. But sometimes the relations among components do not confirm to simple equations. Alternatively, they may fit an equation just fine, but there is no way of knowing what the equation might be. In such cases, simulation models are usually better approach. Simulation is a technique to mimic the operations of various kinds of real world facilities or processes, usually on a computer with appropriate software (Law and Kelton, 2000, Kelton, Sadowski and Sadowski, 2002). Determining the objective of a simulation is a starting point for the process. This is followed by a set of steps to develop the simulation model, and eventually the model is run to generate some results (Schniederjans, 1999). The steps of the simulation process are definition of the problem, formulation of the model, validation of the model, generation of the results after simulation runs, analysis of the results and decision making based on the analysis. Simulation can be expressed in software using conventional programming languages. However, the most cost effective approach is usually to use commercial simulation systems. These systems include graphical tools for building models, automated routines for testing them under different conditions, and reporting tools for analysing the results. Simulators incorporate variability quite naturally which is an important advantage because sales, shipments, prices and countless other aspects vary quite a bit in real world supply chains and this has a major impact on how the supply chains perform. The simulation models handle the variability is by using proper distribution. Although simulations are better than mathematical models at exploring the effects of variability, they are not as good at finding optimal solutions. The best way to handle this in simulation is to vary the value of one or more parameters in a systematic way and look for the one that gives you the best fit. Chopra and Meindl (2003) gave the definition "a supply chain is dynamic and involves the constant flow of information, products and funds between different stages. Each stage of the supply chain performs different processes and interacts with other stages of the supply chain". Managing the supply chain to minimize the system wide cost while satisfying the customer service level requirements is supply chain management. Enterprises have researched under a SCM environment on how to satisfy a customer's various needs considering many uncertain variables with stochastic properties in the supply chain. Existing analytical methods could not treat all variables with stochastic properties in the supply chain and therefore these methods are optimally only able to represent partial supply chains. It is impossible to handle all the dynamically changing supply chain variables using analytical methods. In the analytical method, as the problem size increases, obtaining solutions becomes more difficult. Moreover, even for reasonable sized problems, it is not easy to consider all aspects of the problem in analytical solutions, especially the uncertainty. This is where simulation approach is preferable. It is easier to imitate the real life problem in a simulation model. Simulation approaches take into account the uncertainty of the system. Softwares are available that can be used to build simulation models with great ease. Simulation is known as the most efficient method for dealing with the stochastic variables existing within a supply chain. Simulation is an effective tool for evaluation and analysis of the dynamically changing internal supply chain variables. Moreover it can also work for the global optimisation of planning an entire supply chain with finding local optimum values within each component (Gentry, 1996). Simulation of supply chain networks can be used to predict exactly how a proposed supply chain structure will operate before it is actually implemented. This gives the user the option of thoroughly analysing the supply chain network design, identifying the bottlenecks and optimising the supply chain performance. This optimal design may thereafter be implemented thus maximizing the effectiveness and efficiency. Furthermore, existing supply chain networks can also be evaluated in order to assess as to whether the desired performance levels are being achieved. When a system is designed through simulation, the simulation model is constructed based on one or a combination of the following two methods

- Discrete-event simulation modelling method
- Continuous simulation modelling method

Though product and information flow can have clearly continuous factors in a supply chain, most supply chain problems are usually solved using discrete event simulation modeling method since, real world supply chain systems can be decomposed into a set of logically separate processes which in turn can be simulated as discrete events. Towill *et al.*, 1992 conducted simulation study to analyze the effect of system redesign strategies on the performance of a supply chain. They simulate a supply chain with three echelons: factory, distributor, and retailer. The various strategies tested include the effect of integrating information flow throughout the supply chain and removing the distributor echelon. Swaminathan *et al.*, 1998 studied the influence of sharing supplier capacity information on the performance of a supply chain. They use simulation for comparing different information sharing scenarios after deriving the optimal inventory policy for the manufacturer under stochastic demand.

Inventory management policies prove critical in determining the profits of such firms (Arnold, 1998). It is indeed a major issue in supply chain management (i.e. an approach that addresses supply chain issues under an integrated perspective) (Christopher, 1992 and Lee and Billington, 1992). When inventory decisions in supply chain are made independently at each stage (as it is often the case), they are usually based on the local inventory status and local performance objectives (local policies). Supply chain inventory management (SCIM) is an integrated approach to the planning and control of inventory, throughout the entire network of cooperating organizations from the source of supply to the end user. SCIM is focused on the end-customer demand and aims at improving customer service, increasing product variety, and lowering costs (Zimmermann, 2000). Therefore in SCIM, inventory decisions tend to optimize global performance criteria. The literature identified several means of analysing inventory problems. Each method has strengths and limitations, making their use more suitable to some forms of analysis than others. Simulation has proven itself effective in a variety of applications; here there exists a need to represent in some form the interactions of real world problems (Schriber, 1991). Thomas Schriber argued that simulation bridges the gap between experimentation on the "real system" with its inherent realism, and pure mathematical modeling, and the "increasing abstraction" necessary. Ballou (2004) indicated that, when more than two echelons are involved; managing the inventory throughout the entire chain becomes too complex for mathematical analysis and is usually carried out with the aid of computer simulation. Many of the traditional formulas used to analyze the inventory systems make the assumption that the product demand is certain (i.e. not a random variable). In practice however, demand is rarely known with certainty. Simulation is one of the best means for analyzing inventory systems in which demand is a random variable. Tersine (1994) noted that simulation is useful when it is desirable to experiment with a system, and it is most appropriate when the system is sufficiently complex. Swaminathan *et al.* (1998) described a supply chain-modeling framework that can be used for constructing supply chain simulation models. They have developed software components for representing various types of supply chain agents such as retailers, manufacturers and transporters. They divided the set of elements in their supply chain library into two categories: Structural Elements and Control Elements. Structural elements correspond to agents (i.e. manufacturer agents, transportation agents) and control elements correspond to the control policies. The decisions in supply chain management are classified into two broad categories: strategic and operational. As the term implies, strategic decisions are typically over a long time horizon. 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 manage the product flow in the strategically planned supply chain effectively and efficiently.

6.3.1 Development of simulation model for supply chain inventory planning by using ARENA simulation tool

The software used for simulation is the Arena Standard Edition Simulation software 5.0. This software provides as interactive environment for building, graphically animating, verifying and analysing simulation models for applications ranging from manufacturing to other business processes. Here an interactive module based development is followed and the software inherently generates a Visual Basic code. Based on the manipulations made and the modular logic, the software generates interactive outputs with the help of which a wealth of information is rendered available to the user. With the help of this the user can make useful and informative conclusions about the real life process that is being simulated. For the purpose of modelling a three stage supply chain with objectives as mentioned before several inbuilt modules available in the Arena simulation tool are used. These flowchart and data modules are available in the various process panels and can be selected from the panel window. A complete listing of the various modules used and their corresponding panels are listed in the table 6.19. The top-level model is shown in figure 6.4. In addition to the above mentioned modules the navigate panel is used to navigate between the various sub-modules which have been used extensively to ensure that understanding as well as expansion of the model is made comparatively easier. The report panel is used to view output reports.

Table 6.19: Data/flowchart modules used in ARENA simulation tool

<table>
<tr><th>Module</th><th>Panel</th></tr>
<tr><td>Create</td><td rowspan="11">Basic Process</td></tr>
<tr><td>Dispose</td></tr>
<tr><td>Process</td></tr>
<tr><td>Decide</td></tr>
<tr><td>Batch</td></tr>
<tr><td>Separate</td></tr>
<tr><td>Assign</td></tr>
<tr><td>Record</td></tr>
<tr><td>Resource</td></tr>
<tr><td>Variable</td></tr>
<tr><td></td></tr>
<tr><td>Delay</td><td rowspan="4">Advanced Process</td></tr>
<tr><td>Hold</td></tr>
<tr><td>Release</td></tr>
<tr><td>Signal</td></tr>
<tr><td>Station</td><td></td></tr>
</table>

Request	
Free	
Transport	Advanced Transfer
Transporter	
Distance	

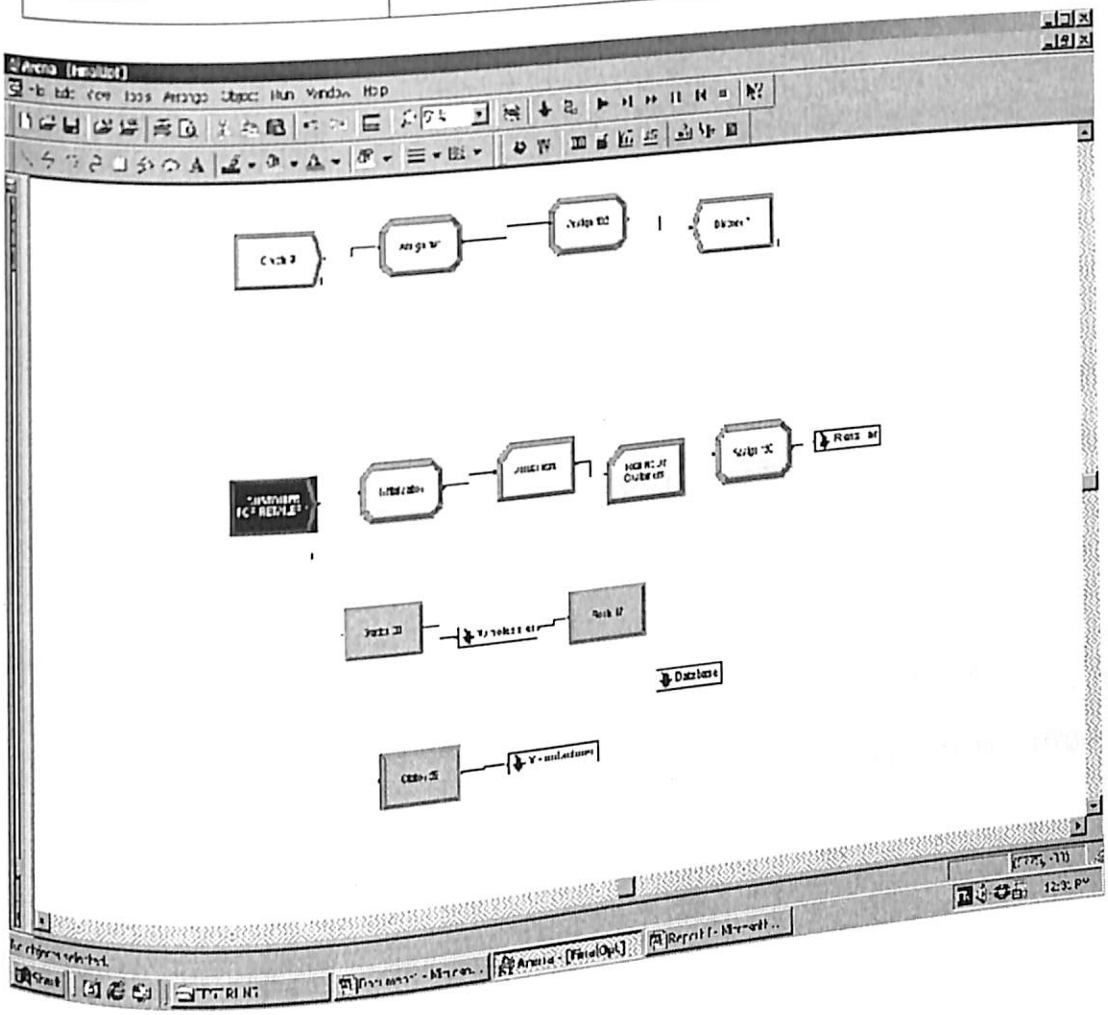


Figure 6.4: Top level model in ARENA

6.3.1.1 Assumptions

The assumptions of the model are given below:

- The supply chain considered is serial supply chain with one retailer, one distributor and one manufacturer.
- One product is produced at the manufacturer in continuous production.

- It is considered the distance between the distributor and retailer is 50 km.
- It is considered the distance between the manufacturer and distributor retailer is 50 km.
- The continuous-review inventory policies are adopted at retailer and distributor.
- Average inventory held at each point is calculated as the average of starting inventory and ending inventory each day.

6.3.1.2 Input parameters

To run the model, various input parameters are considered for the different members of the supply chain. The details are given below. The model is simulated for 30 days considering the supply chain is operating for 16 hours/day. The input parameters for customer are given below:

- Customer arrival rate is a Poisson distribution with a mean of 5.
- Customer order quantity is a triangular distribution taking integer values between 1 and 5 with a mean of 3.

The Input parameters for retailer are given below:

- One aisle with one shelf containing a maximum of 20 products.
- Aisle routing time is a normal distribution with a mean of 2 minutes and a standard deviation of 1 minute.
- Three are three billing counters with three clerks.
- Counter and clerk are assigned on the basis of occupancy.
- To start with simulation, the initial inventory is taken as order quantity.
- Only one customer is allowed interaction with the shelf at any instant.

- Process delay during billing is a normal distribution with a mean of 5 minutes and a standard deviation of 3 minutes.
- Order placing time to distributor is a normal distribution with a mean of 10 minutes and a standard deviation of 2 minutes.
- One inbound station exists for entering transporters to dock.

The input parameters for distributor are given below:

- Order quantity and re-order points are multiples of retail re-order quantity.
- To start with simulation, the initial inventory is taken as order quantity.
- Order processing time is a normal distribution with a mean of 10 minutes and a standard deviation of 2 minutes. One clerk is used.
- Unsatisfied orders are held until sufficient inventory is procured.
- Order placing time to manufacturer is a normal distribution with a mean of 10 minutes and a standard deviation of 2 minutes.
- One inbound station exists for in-coming transporters.
- One outbound station exists for out-going transporters.

The input parameters for manufacturer are given below:

- Order processing time is a normal distribution with a mean of 10 minutes and a standard deviation of 2 minutes. One clerk is used.
- Unsatisfied orders are held until sufficient inventory is procured.
- One outbound station exists for out-going transporters.
- Production rate is set according to Analysis Procedure.
- To start with simulation, the initial inventory is wholesale re-order point.

The input parameters for transporters are given below:

- The velocity of the transporter is 50 km/h.
- TL Carriers are used that vary cost only on the basis of distance and overall capacity but irrespective of capacity utilization.
- The distributor- retailer transporter truck capacity is 600 products.
- The manufacturer – distributor transporter truck capacity is1200 products.
- Number of transporters depends on order quantity. If order quantity exceeds net capacity of current number of transporters, an additional transporter is used.
- Transporter units are used for satisfying only one order at a time.

The input parameters for cost are given below:

- Costs taken into consideration for profit calculation are product selling price, production cost, holding cost, and transportation cost.
- Stock-out costs are considered as stock-out losses. These are calculated as the amount of additional profit had stock-outs been prevented.
- Costs are calculated at the end of every working day.
- The selling price of product is 10 units/ product.
- The production cost is 2 units/ product (i.e. 20% selling price).
- The holding cost is 0.5 units/ product (i.e. 5% selling price).
- Transport cost is calculated on the basis of maximum capacity of each transporter. Lower orders will still be charged this maximum price. Unit prices are defined for 50 km. of distance. Manufacturer – distributor

transporters therefore charge threefold that of distributor – retailer transporters.

- Transport cost = 0.5 units/product/50 km. (5% selling price).
- Distributor – retailer transport cost = Transport cost* maximum capacity= 0.5 * 600 = 300 units/truck
- Manufacturer – distributor transport cost = 0.5 * 1200 * 3 = 1800 units/truck.

6.3.1.3 Retailer sub-model

The retail shops are structured as in real life with an aisle containing the shelf of products. Inventory levels in the retailers are maintained at two degrees. There is the main retail inventory, which is the stock that the retailer keeps in store for the product. There is also the secondary shelf inventory from which the customer actually picks the product depending on how many he needs. At each shelf, the number of orders the customer has for the product is first compared with the current shelf inventory. In the case of there being sufficient shelf inventory, the customer picks his product and that amount is now decremented from the shelf. The customer order fill rate is also calculated at this stage. A normally distributed process time is also defined for the picking process so as to take into account possible real-life delays. If the shelf inventory is not sufficient, it is assumed that the customer will pick up at least the amount that remains and not leave unsatisfied. The attribute that defines the number of orders for that product is now reassigned to this new value. The shelf is assigned a stacking point, which initiates the re-filling of the shelf. In the event of being no products on the shelf, the number of orders of that customer is added to the number of retailer stock-outs. If the customer is partially satisfied, the unsatisfied number of orders is added to the same. If the lead time on tag is activated, unsatisfied orders are added to the current lead time demand. The average lead time demand during each order is reported. After the picking process is complete, the customers arrive at the billing counters area, which contains 3 billing counters. The counter to which they must go to get billed is chosen by the pick station module which will send a particular customer to the billing counter with the least people already in queue and the least en route to it. In this way, efficiency is maintained. Once the customer is at the counter, a retailer clerk resource processes the order. The processing of each order takes place in the following way. The shelf inventory is first checked as to whether it is has reached its stacking point. If it has, a pre-decided amount (called Preshelf) is subtracted from the main inventory and added to the shelf inventory. The main inventory is then compared with the re-order point (ROP) and a check is also performed as to whether an order to the distributor (if needed) has been placed already. If ROP has been reached and an order needs to be placed, the entity now becomes a retail order entity and proceeds to the distributor. The re-order placed tag and lead time on tag are now activated. The inbound at each retailer accepts the order when the transporters bring him or her in. The inventory is then incremented by the necessary amount and the re-order placed tag is reset. The transportation cost is calculated at this stage. The average lead time is also determined after each order. The retailer sub model is shown in figure 6.5.

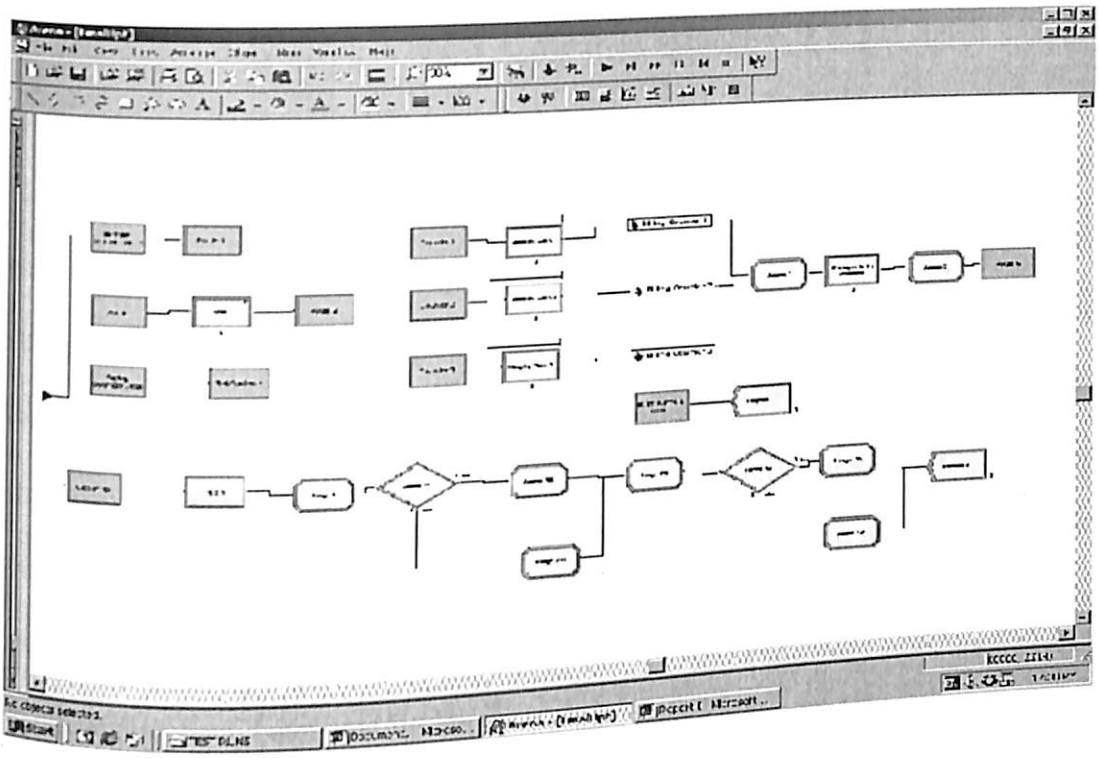


Figure 6.5: Retailer sub-model in ARENA

6.3.1.4 Distributor sub-model

The arriving entity for the wholesale sub models is the retail order. Here too, as in the retail level, a decide module is first used to check if the wholesale inventory level is greater than the retail order quantity. If it is, then the retail order is processed, the wholesale inventory level is decremented and the number of retail orders satisfied is recorded. The retail order fill rate is also calculated at this point. The resource used to carry out the process is labeled as a distributor and the number of resources can be set as required. If the wholesale inventory level is less than the retail order, then it is considered as a stock out and the number of stock-outs is recorded. At this stage, a hold module is used to ensure that the retail order waits at the distributor until the re-order from the manufacturer arrives. The average waiting time for each retail order is calculated. At this point, a separate module is used to ensure that while the entity waits, simultaneous reorder may also take place. At the wholesale level too, a continuous review inventory policy is followed. Thus after each decrement in the wholesale inventory level, a check is made to determine if it has fallen below a predetermined ROP. If it has then a check is made again to see if and order has already been placed and is in transit. When this condition is not satisfied an order is placed to the manufacturer and a wholesale lead-time attribute is initialized to the current simulation time. Finally, the entity type is now reset to wholesale order and the control flows out of the wholesale sub model. The wholesale warehouse is divided into two separate types of stations, one for inbound goods and a set of stations for outbound goods. At the outbound stations a transporter picks up the retail order and delivers it to the retailer. At the inbound station, yet another transporter unloads the goods, which have been sent by the manufacturer. Thereafter the wholesale inventory level for that product is incremented by the wholesale order quantity. The lead-time attribute is recorded to estimate the mean lead-time for the distributor orders. The transportation cost is also calculated. The distributor sub-model is shown in figure 6.6.

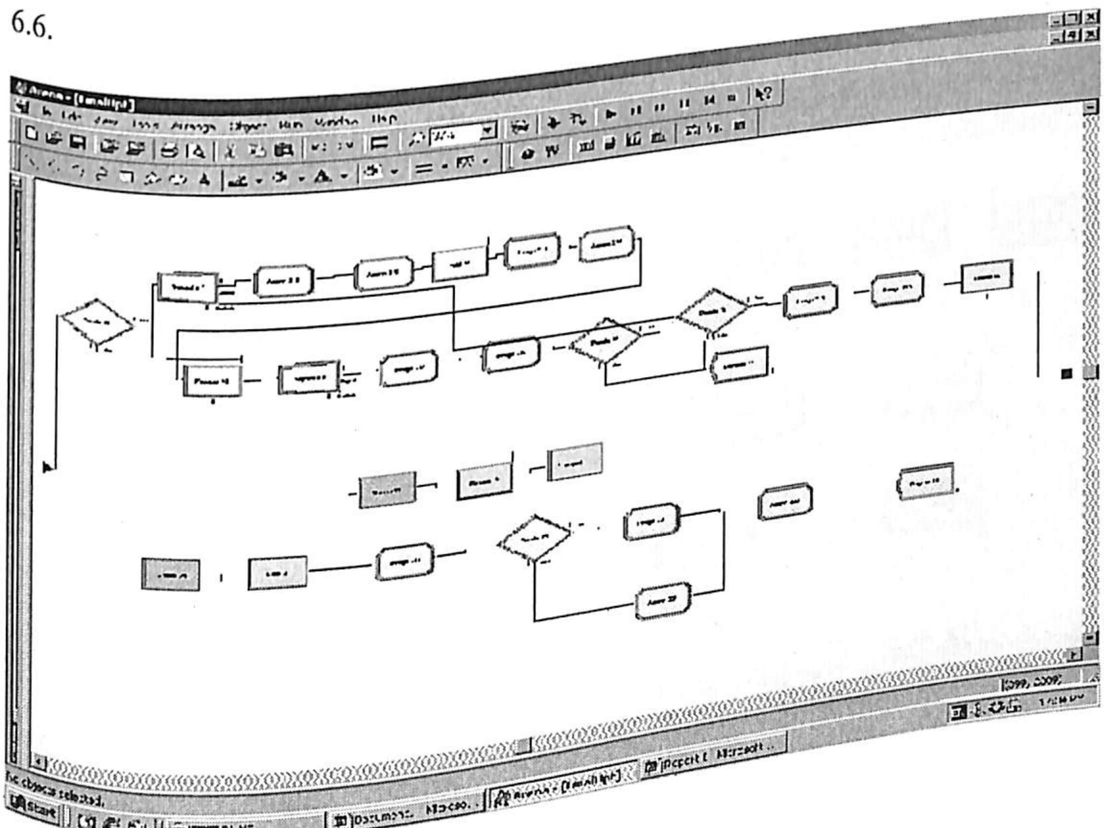


Figure 6.6: Distributor sub-model in ARENA

6.3.1.5 Manufacturer sub-model

The logic used to simulate the processes at the manufacturer is similar to that of the retail and wholesale sub models. The manufacturer produces the product by continuous production. The agglomerated raw materials are assumed to arrive together and the arrival rate is set in the create module. Consequently, a process module is used to simulate final assembly or production of the product. The production time is determined experimentally. The resource used for this process is labeled as manufacturer. Thereafter the finished products are batched and then moved to the factory warehouse and thus the factory warehouse inventory level is continuously incremented. The production cost is calculated here. The inventory level check is performed for arriving wholesale orders. If the distributor can be satisfied, a transporter then performs the task of transporting the wholesale order quantity back. The successful satisfying of the order is recorded and the wholesale order fill rate is calculated. In the case of a stock-out, the order is made to wait at the manufacturer and a corresponding average waiting time is calculated. The manufacturer sub model is shown in figure 6.7.

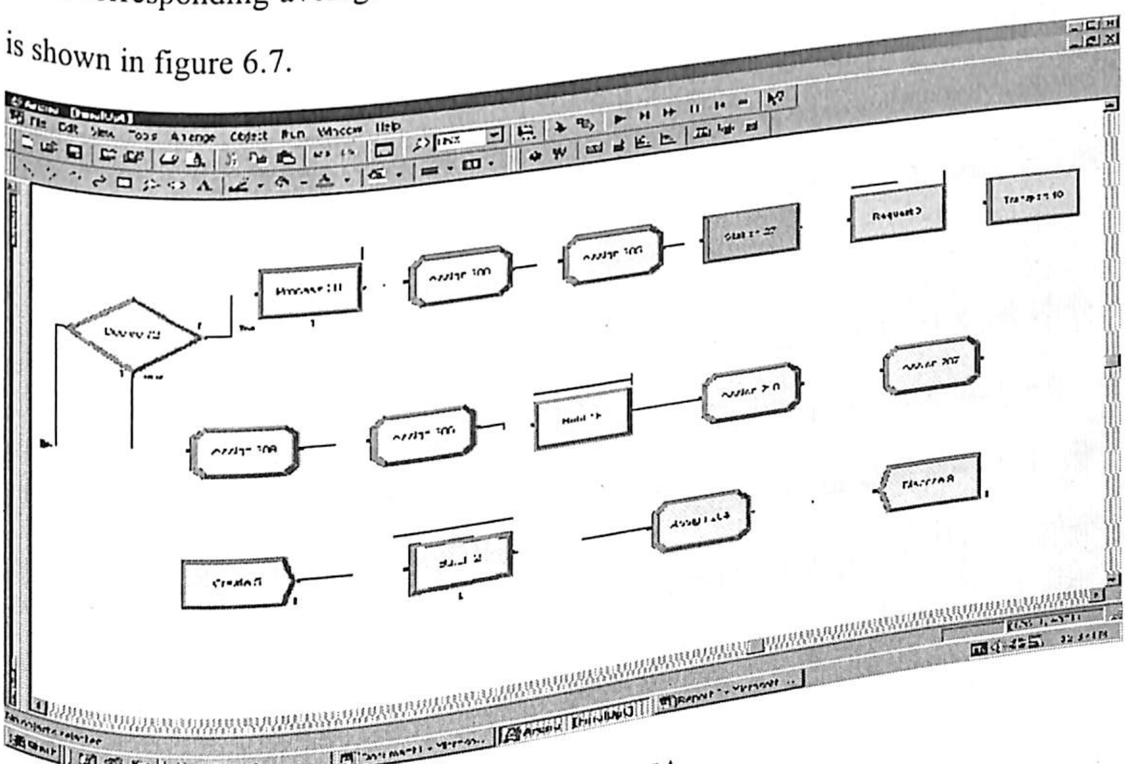


Figure 6.7: The manufacturer sub model in ARENA

6.3.1.6 Results and discussion

All costs are calculated on a daily basis in the supply chain. A separate create module is used to engage a single entity at the end of each day to perform the cost calculations. The following are the costs considered and their calculation procedures:

- Production cost: This cost is added per product produced at the manufacturer.
- Holding cost: Each day, the average inventory is calculated for each stage as the average of the day's starting and ending inventory. This is then multiplied with the per product charge and cumulatively added over the days.
- Transportation cost: The transportation costs are calculated at the time of arrival of a transporter. However, they are added to the overall expenditure only at the day's close. At the retailer and distributor stages, the number of arriving transporters is first calculated on the basis of the order quantity and the corresponding transporter's maximum capacity. The charge per truck is then multiplied with this number to establish the overall transport charge. Distance is also multiplied as units of 50 km.
- Stock-out Loss: The number of stock-outs at the retailer is calculated in the retailer sub model. This number is then multiplied with a quantitative ratio that represents percentage of product price to profit. The resulting value therefore indicates how much the stock-out products would have contributed additionally to the current profit. This cost is not added to the overall cost, as this is not considered to be expenditure.

- Total expenditure: The sum of the cumulative production, holding and transportation costs are reported as the net expenditure of the chain.
- Total Sales: The overall demand minus the number of retail stock-outs gives a measure of total satisfied demand. This multiplied by per product selling price gives net earnings of the chain.
- Profit: The total expenditure is subtracted from the total sales to determine profit at the end of each working day.

The methodology involved in actually setting the operating parameters of the supply chain by conducting several experiments. The order prescribed avoids repetitive runs as well as irrelevant experiments. All the information was obtained from the simulation-time database at the end of each run. The procedure for determining optimal operating point is as follows:

- Determination of production rate: Initially the simulation starts with zero values at different points to determine the demand forecasting. These values are assumed then to be the forecasted demand for the simulation runs to follow. The ideal production rate is then set by determining the time necessary per product so as to produce as near this amount as possible during the simulation run.
- Determination of retail re-order point: arbitrary values are taken for all parameters of the chain. The initial re-order point is set at a low value. The simulation is then run and the customer order fill rate (COFR) and the lead time demand are determined. As this demand is a measure of number of orders unsatisfied during lead time, this quantity is added to the present re-order point. The resulting value is then used for simulation. This procedure is followed until incrementing the value no longer affects the values of the

measures. The minimum point at which the performance measures stabilize is the ideal retail re-order point (RROP). The tabulated results show a gradual increase in the values of re-order point. This was done to show the movement trends in the performance measures. Far fewer runs are truly required to determine re-order point). From this point onwards, each retail order quantity (and therefore retail initial inventory) is dealt with in an isolated manner. The following experiments are performed to find retail reorder quantity as given below:

RROP	50	80	100	120	140	160
COFR	70	82	90	96	98	98

- Determination of wholesale re-order point: the values of retail order quantity and retail re-order point are set. The wholesale order quantity is assumed as an arbitrary multiple of retail order quantity. The wholesale re-order point is first set at zero and then at increasing multiples of the retail order quantity. For each such setting, a simulation run is performed and the retail order fill rate is measured. The point at which this value becomes 100% determines the wholesale re-order point.
- Determination of wholesale order quantity: once the above parameters have been set, the wholesale order quantity (and therefore wholesale initial inventory) is varied from the minimum possible value (wholesale re-order point) to as high as necessary. The increments are all as multiples of retail order quantity. For each value, the simulation results for profit are determined and the optimal point is decided as that of highest profit (see table 6.20-6.26 and figure 6.8-6.14).

Table 6.20: Profits in the supply chain for retail order = 200

Distributor order	THC	TTC	TC	PROFIT
400	14846	100800	152556	16813
600	19086	73500	129896	38353
800	22196	62700	122606	45923
1000	25701	53700	117511	50328
1200	**26286**	**50400**	**115196**	**54623**
1400	30716	64500	134126	34223
1600	36036	60900	136246	32343
1800	34256	57600	131566	39423
2000	38521	54000	132631	37748
2400	48481	46200	135591	31088
2800	54711	57300	153721	14678

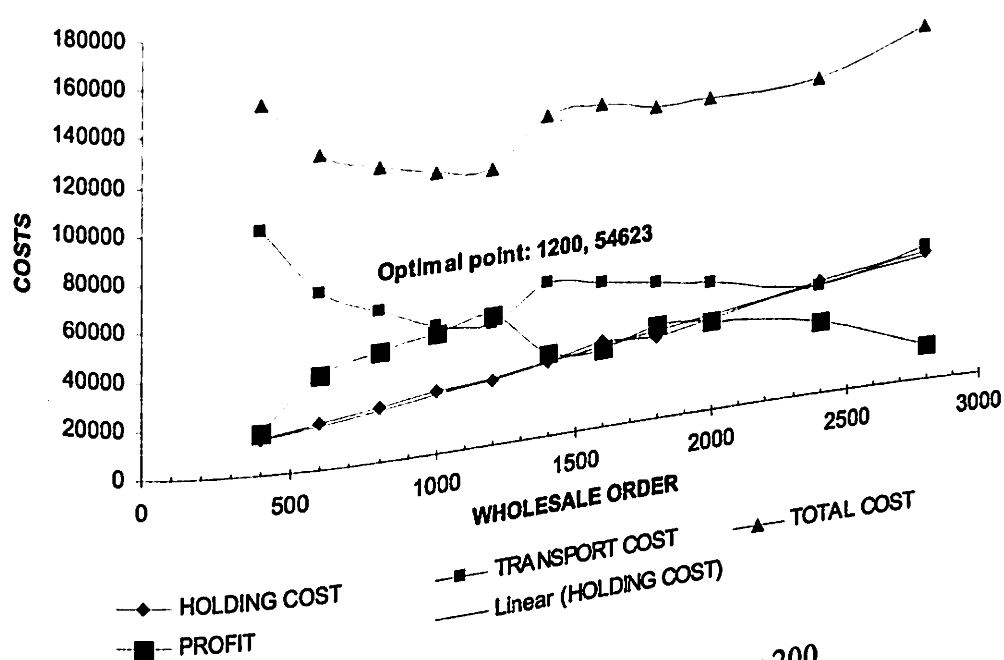


Figure 6.8: Profits in the supply chain for retail order = 200

Table 6.21: Profits in the supply chain for retail order = 300

Distributor order	THC	TTC	TC	PROFIT
300	14016	115500	166266	2463
600	19826	65100	122236	45463
900	25831	48600	112341	54408
1200	**27401**	**39900**	**105811**	**62618**
1500	33436	56100	128646	39763
1800	36586	49200	125496	45633
2100	43836	41700	125846	42913
2400	46931	38100	125941	41958
2700	54316	48900	144726	23363

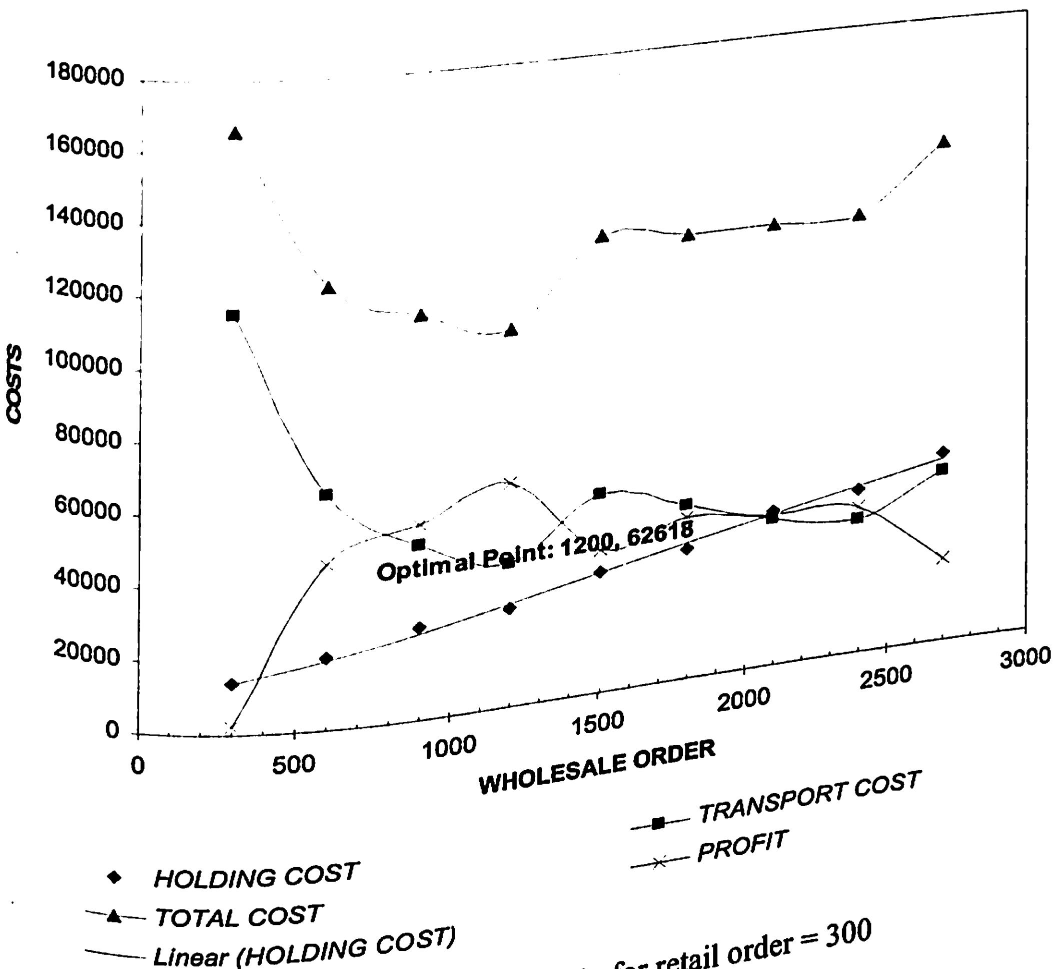


Figure 6.9: Profits in the supply chain for retail order = 300

Table 6.22: Profits in the supply chain for retail order = 400

Distributor order	THC	TTC	TC	PROFIT
400	19391	86100	142801	24668
800	**22821**	**50400**	**111311**	**60708**
1200	32761	35700	107371	59558
1600	38141	48300	126151	42108
2000	41971	41400	123881	47888
2400	48671	34200	124181	46058
2800	51991	39300	133401	36128

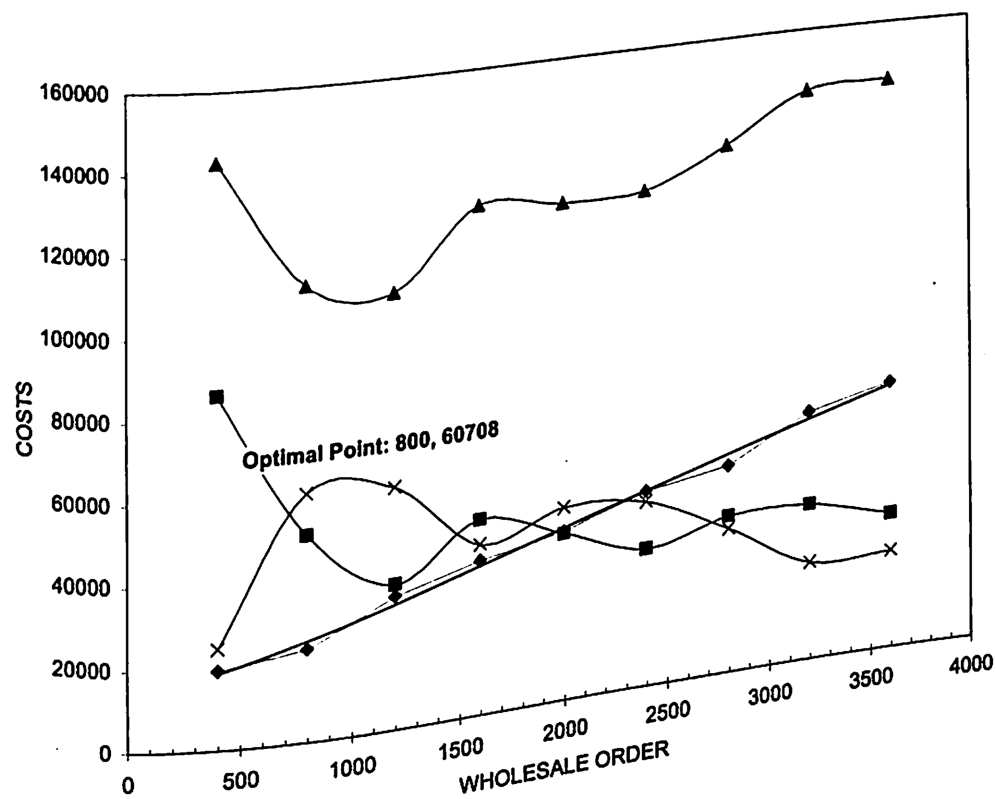


Figure 6.10: Profits in the supply chain for retail order = 400

Table 6.23: Profits in the supply chain for retail order = 500

Distributor order	THC	TTC	TC	PROFIT
500	23501	69300	130711	37238
1000	**31796**	**38700**	**109406**	**58843**
1500	39706	49500	128486	41113
2000	47521	38400	126831	40478
2500	53166	42300	137376	31553
3000	60991	36900	140801	27858
3500	69996	31500	145406	22213
4000	76141	38700	159751	9968

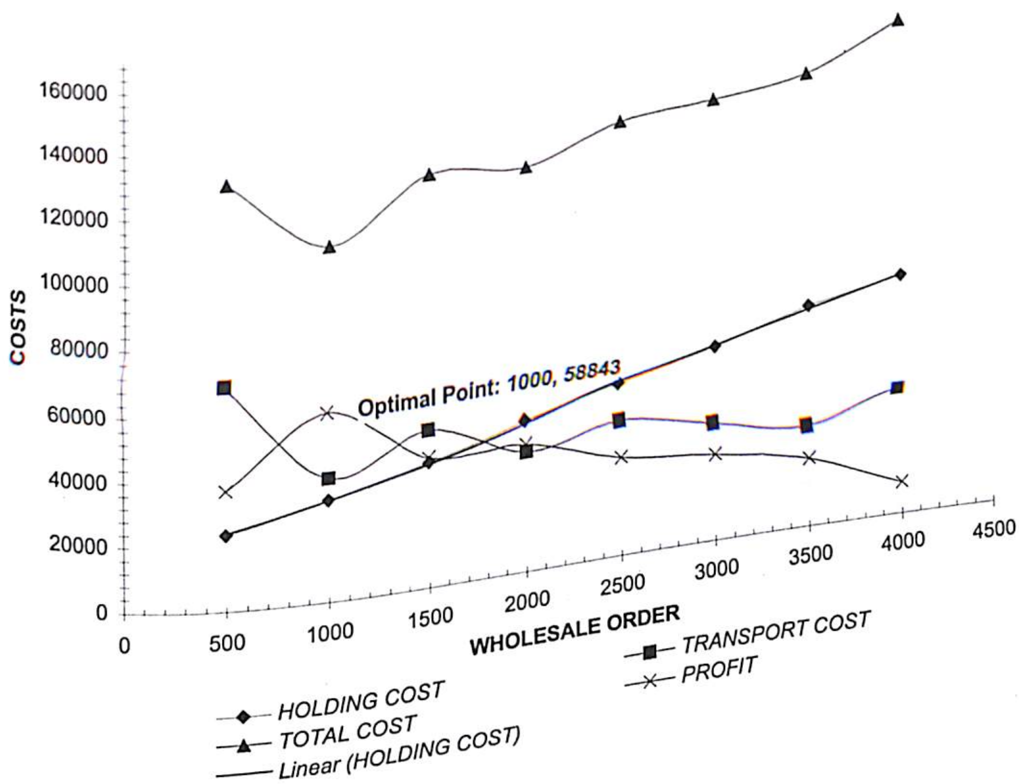


Figure 6.11: Profits in the supply chain for retail order = 500

Table 6.25: Profits in the supply chain for retail order = 700

Distributor order	THC	TTC	TC	PROFIT
700	**33321**	**55200**	**127631**	**41198**
1400	46176	53400	140086	26323
2100	56196	39000	137106	29793
2800	62906	40800	147016	21483

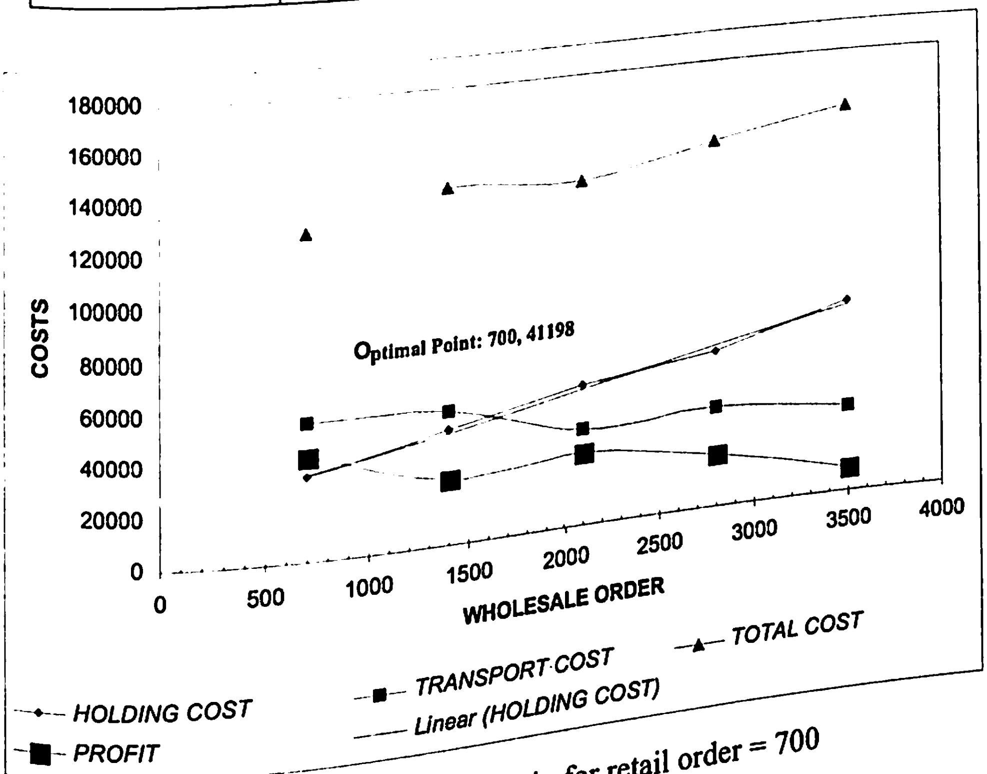


Figure 6.13: Profits in the supply chain for retail order = 700

Table 6.26: Profits in the supply chain for retail order = 800

Distributor order	THC	TTC	TC	PROFIT
800	**37501**	**48000**	**125221**	**42958**
1600	51131	48000	140441	26808
2400	62816	33600	139326	28843
3200	77626	39000	161136	5693

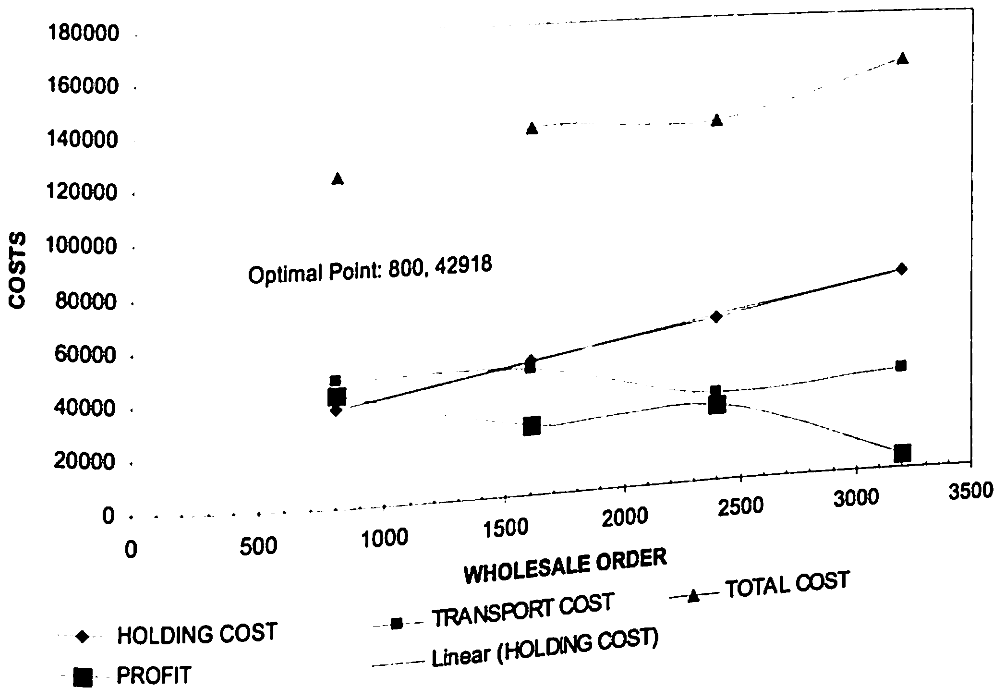


Figure 6.14: Profits in the supply chain for retail order = 800

- Determination of optimal operating point: the optimal points for each retail order are graphically compared. The point with the highest **Profit** determines the operating point of the supply chain for the given demand distribution (see figure 6.15 and table 6.27).

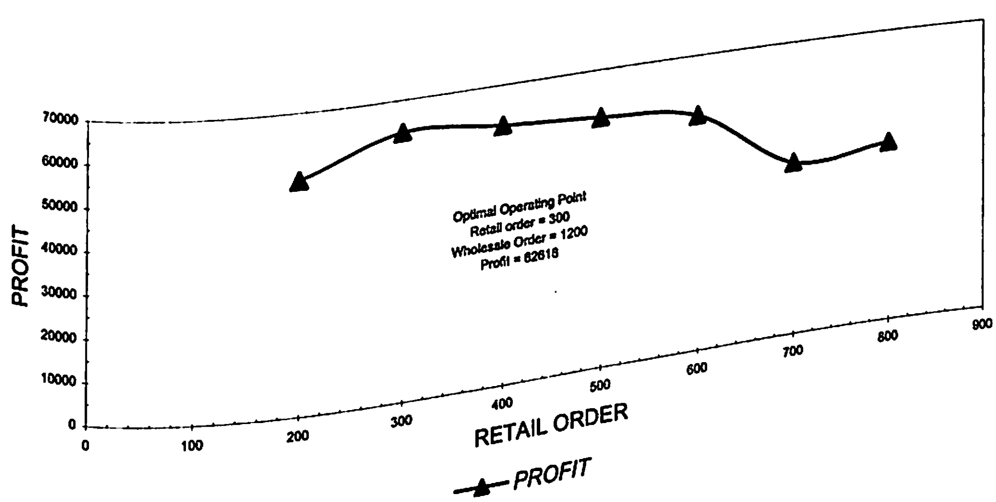


Figure 6.15: Maximum profits in the supply chain for different retail order

Table 6.27: Maximum profits in the supply chain for different retail order

Retailer order	200	300	400	500	600	700	800
Profit	54623	62618	60618	58843	55833	41198	42958

The overall demand in the supply chain is found out to be 17300 units for overall simulation run-time of 28800 minutes, which gives ideal production rate to be 1.65 minutes/product. The optimal operating point in the supply chain is found out as

- Retail re-order point: 140
- Wholesale re-order point: 300
- Retailer order: 300
- Wholesale order = 1200
- Manufacturer initial inventory: 300

The following are the broad conclusions are drawn from the test run values:

- Lead time demand and customer order fill rate stabilized beyond a particular re-order point at the retailer stage. The choice to set this value was to ensure that for maximum performance, there would be minimum average inventory held.
- Total holding cost always increased linearly, as expected.
- As order size increased, the transportation cost decreased as expected. However, as the transporters had capacity limits, the usage of an additional unit caused a dramatic rise in the transportation cost. Further increases in order size brought this cost down until the next transport unit was added. Total cost lines followed very closely with the fluctuations in transportation cost.

The following are a few cases that best illustrate how conclusions may be drawn from the values obtained in the experiments. They deal with the actual test run values and offer an explanation for the trends observed.

- Case 1: Retail order = 200, Wholesale order = 400: the low order quantities ensured that the holding costs were low but at the same time caused the number of transport trips to increase dramatically. This caused an abnormally high transportation cost, which accounts for the low profit.
- Case 2: Retail order = 200, Wholesale order = 600, 800, 1000, and 1200: the trend clearly shows the increase in holding cost and decrease in transportation cost. The number of trips reduced as the order size increased thereby bringing the costs down. However, it is only at a wholesale order of 1200 that the transporter is running at maximum capacity.
- Case 3: Retail order = 200, Wholesale order = 1400: the minor increase in order size here over shot the capacity of a single transporter. A second transporter was thus added to transport the additional 200 units. However, the charges of the transporters were still on the basis of maximum capacity (see assumptions). The transportation cost is therefore extremely high due to both the additional transporter and the need for several transport trips.
- Case 4: Retail order = 200, Wholesale order = 1600, 1800: transportation costs reduced with a decrease in the number of trips, although full truck charges were still implemented for less than full-capacity transports.

- Case 5: Retail order = 200, Wholesale order = 2000, 2400: the transportation costs reduced as full capacity was reached with a reduction in number of trips. However, the large holding costs offset this reduction to result in low profits. Further, the production costs of initial inventory added greatly to the total cost.
- Case 6: Retail order = 500, Retail order = 700: in the case of both these order quantities, the possible wholesale order values could never maximally occupy a transporter. The maximum profit in both these cases is therefore not nearly as high as for the previous cases.
- Case 7: Retail order = 800: in this case, the overall cost shows no real reducing trend at any point due to the high holding costs. The production cost of initial inventory is also very high for each of these wholesale order values resulting in high total cost.
- Case 8: Retail order = X, Wholesale order > 4000: in all such cases the fourth additional transporter, the overall holding costs and the huge initial inventory production cost cause extremely low profit values, irrespective of retail order quantity.

6.3.2 Development of simulation model for inventory performance measures by using ARENA simulation tool

A simulation model is developed for a serial supply chain consisting of multiple retailers, distributors/wholesalers and manufacturers. Here all the retailers and wholesalers follow a continuous review inventory policy as stated earlier. Each retailer is assumed to have a group of 10 products taken from a pool of 30 known products. Wholesalers will have any combination out of those 30. The difference here lies in the fact that retailers often have over-lapping products whereas in both wholesaler and manufacturer stages, the products are present only at unique venues. Manufacturers produce 6 products each in continuous production. The starting point of the model is the arrival of customers. The customer arrivals rates are set for each of the retailers with the help of corresponding create modules and are normally distributed. Initially the entity type is set as the customer. Each customer is then assigned a set of attributes that govern the number of each product the customer has arrived to purchase. It is assumed at this stage that customers arriving at particular retailers will have a need only for that retailer's products. The number of orders for each product (per customer) is random and is achieved using a discrete probability distribution along with a triangular distribution. Thereafter the mean arrival rate and the number of customers entering the retailer are recorded with the help of record modules. After that, the arriving customers enter the retail sub models. A sub model aggregates the logic concerning a particular process thus enabling easy navigating through the model especially as the complexity involved increases. Separate sub models are used for each of the retailers, wholesalers and manufacturers. The logic involved in each of these three sub models is explained below.

6.3.2.1 Retailer sub-model

Customers arrive at each retail shop at normally distributed rates. After the assigning of random product orders is performed (i.e. each customer decides how much of each product he wishes to buy), the customer enters the shop. The retail shops are structured as in real life with aisles containing shelves of products. As has been mentioned, each retailer contains a random 10 products and customers arriving are in need only of those 10 at that retailer. The need for a product may also be nil (with a 40% chance as set in the discrete probability) in which case the customer is simulated to merely walk by a particular shelf without picking up a product. Inventory levels in the retailers are maintained at two degrees. There is the main retail inventory which is the stock that the retailer keeps in store for each product. There is also the secondary shelf inventory from which the customer actually picks the products depending on how many he needs. At each shelf, the number of orders the customer has for that shelf's product is first compared with the current shelf inventory. In the case of there being sufficient shelf inventory, the customer picks his product and that amount is now decremented from the shelf. The fill rate is also calculated at this stage. A normally distributed process time is also defined for the picking process so as to take into account possible real-life delays. If the shelf inventory is not sufficient, it is assumed that the customer will pick up at least the amount that remains and not leave unsatisfied. The attribute that defines the number of orders for that product is now reassigned to this new value. At this time the shelf inventory becomes zero. For arriving customers beyond this period, a shelf stock-out counter is maintained. The aisles are all treated as named stations and the customers traverse from one station to another sequentially. After the entire picking process is complete, the customers arrive at the billing counters area which contains 3 billing counters. The counter to which they must go to get billed is chosen by the pick station module which will send a particular customer to the billing counter with the least people already in queue and the least en route to it. In this way, efficiency is maintained. Once the customer is at the counter, a retailer clerk resource processes the order. The billing process constitutes the most complex part of the model. The number of orders of each customer is processed one after the other; at the conclusion of which the customer leaves the store. The processing of each order takes place in the following way. The shelf inventory is first checked as to whether it is empty or not. If it is empty, a pre-decided amount (called Preshelf) is subtracted from the main inventory and added to the shelf inventory of that particular product. The main inventory is then compared with the ROP and a check is also performed as to whether order (if needed) has been placed already. If no order needs to be placed, the next product is processed. If ROP has been reached and an order needs to be placed, a separate module is used to create a duplicate of the entity. One of the duplicates continues the product processing for the remaining products that the customer may have bought. The other duplicate now becomes a retail order entity and stores an attribute corresponding to the product that needs to be ordered and another entity naming the retailer that the order comes from. An order check is assigned after which the entity then proceeds to the wholesaler sub-model for further processing. The inbound at each retailer accepts the orders when the transporters bring them in. The inventory is then incremented by the necessary amount and the order check is reset.

6.3.2.2 Wholesaler sub-model

The arriving entities for the wholesale sub-models are the retail orders. The retailers to be supplied by a particular wholesaler are assigned an attribute with the help of which they can easily be identified. The product number corresponds to a particular index of each wholesaler. This index is the basis for all calculations in this sub-model. The queues for waiting retail orders are in the form of queue sets and products of each wholesaler index are made to wait in their corresponding queue. Here too, as in the retail level a decide module is first used to check is the wholesale inventory level for that product is greater than the retail order quantity for the retail order concerned. This retail order value is stored in a 20x5 matrix as it must account for the products present in all retailers. If it is, then the retail order is processed, the wholesale inventory level is decremented and the number of retail orders satisfied is recorded. The resource used to carry out the process is labeled as a wholesaler and the number of resources can be set as required. If the wholesale inventory level is less than the retail order, then it is considered as a stock out and the number of stock-outs is recorded. At this stage, a hold module is used to ensure that the retail order waits at the wholesaler until his reorder arrives. A wait-time has also been calculated for each product in wholesaler. At this point, a separate module is used to ensure that while the entity waits, simultaneous reorder may also take place. At the wholesale level too, a continuous review inventory policy is followed. Thus after each decrement in the wholesale inventory level for a particular product, a check is made to determine if it has fallen below a predetermined ROP. If it has then a check is made again to see if and order has already been placed and is in transit. When this condition is not satisfied an order is placed to the manufacturer and a wholesale lead time attribute is initialized to the current simulation time. Finally, the entity type is now reset to wholesale order and the control flows out of the wholesale sub-model. An attribute is also defined here which identifies the number of the wholesaler from which the order arrives. The wholesale warehouse is divided into two separate types of stations, one for inbound goods and a set of stations for outbound goods. At the outbound stations a transporter picks up the retail order and delivers it to the specific retailer which can be identified by its unique attribute as stated earlier. The transporter is picked from a pool of transporters assigned to each wholesaler on the basis of the product to be transported. At the inbound station, yet another transporter unloads the goods which have been sent by the manufacturer. Thereafter the wholesale inventory level for that product is incremented by the wholesale order quantity. The lead time attribute is recorded to estimate the mean lead time for the wholesaler as well as to determine the mean lead time demand. The inbound and outbound stations are station modules and are labeled with unique station numbers. The distances between the manufacturer outbound the attribute assigned earlier. Here too, the transporter is chosen from a pool assigned to the manufacturer on the basis of the product. The successful satisfying of the order is recorded. In the case of a stock-out, the order is made to wait at the manufacturer and a corresponding wait-time is calculated.

6.3.2.4 Input parameters

A complete sample problem with inputs from the user interface is taken and simulated so as to get a perception of performance of the supply chain configuration of 5*5*8 where 5 stands for number of manufacturer, 5 stands for number of wholesalers and 8 stands for number of retailer. The simulation run length is 30 days. The common inputs to retailers are as follows:

- Customer arrival rate : NORM(2,1) min (where NORM: Normal distribution)
- Number of orders per product per customer :ANINT(NORM(3,2))
- Aisle routing time: NORM(2,1) min
- Product picking time per shelf : NORM(2,1) min
- Billing time : NORM(5,3) min
- Retail re-order placing time : NORM(10,2) min

The retailer specific inputs are given in table 6.28-6.35.

Table 6.28: Input parameters for Retailer 1

Product number	Initial inventory level	Re-order point (units)	Order quantity (units)
1	100	25	100
4	100	25	100
9	100	25	100
12	100	25	100
14	100	25	100
18	100	25	100
22	100	25	100
25	100	25	100
28	100	25	100
29	100	25	100

Table 6.29: Input parameters for Retailer 2

Product number	Initial inventory level	Re-order point (units)	Order quantity (units)
2	200	40	200
5	200	40	200
8	200	40	200
11	200	40	200
15	200	40	200
17	200	40	200
20	200	40	200
24	200	40	200
26	200	40	200
30	200	40	200

Table 6.30: Input parameters for Retailer 3

Product number	Initial inventory level	Re-order point (units)	Order quantity (units)
4	175	30	175
7	175	30	175
10	175	30	175
13	175	30	175
15	175	30	175
19	175	30	175
21	175	30	175
23	175	30	175
27	175	30	175
29	175	30	175

Table 6.31: Input parameters for Retailer 4

Product number	Initial inventory level	Re-order point (units)	Order quantity (units)
3	300	40	300
6	300	40	300
8	300	40	300
11	300	40	300
14	300	40	300
17	300	40	300
22	300	40	300
25	300	40	300
28	300	40	300
30	300	40	300

Table 6.32: Input parameters for Retailer 5

Product number	Initial inventory level	Re-order point (units)	Order quantity (units)
2	250	50	250
5	250	50	250
9	250	50	250
12	250	50	250
15	250	50	250
16	250	50	250
18	250	50	250
20	250	50	250
24	250	50	250
27	250	50	250

Table 6.33: Input parameters for Retailer 6

Product number	Initial inventory level	Re-order point (units)	Order quantity (units)
2	100	30	100
4	100	30	100
9	100	30	100
13	100	30	100
16	100	30	100
19	100	30	100
21	100	30	100
23	100	30	100
26	100	30	100
30	100	30	100

Table 6.34: Input parameters for Retailer 7

Product number	Initial inventory level	Re-order point (units)	Order quantity (units)
1	300	45	300
5	300	45	300
7	300	45	300
11	300	45	300
14	300	45	300
17	300	45	300
19	300	45	300
22	300	45	300
24	300	45	300
27	300	45	300

Table 6.35: Input parameters for Retailer 8

Product number	Initial inventory level	Re-order point (units)	Order quantity (units)
3	200	40	200
6	200	40	200
7	200	40	200
10	200	40	200
12	200	40	200
16	200	40	200
18	200	40	200
21	200	40	200
25	200	40	200
26	200	40	200

The common inputs to wholesaler are as follows:

- Retail order processing time: NORM(10,2) min
- Wholesale re-order placing time: NORM(10,2) min

The wholesaler specific inputs are given in table 6.36.

Table 6.36: Input parameters for wholesalers

Wholesaler number	Product distribution	Initial inventory	ROP
1	1, 3, 5, 6, 15	2000	500
2	2, 4, 8, 10, 12, 13, 18, 20	2000	600
3	7, 9, 11, 14, 16, 17, 19	2500	1000
4	21, 25, 26, 29, 30	2000	750
5	22, 23, 24, 27, 28	3000	1250

The common inputs to manufacturers are as follows:

- Production rate per product: NORM(2,0.2) min
- Initial manufacturer inventory per product: 20000

The manufacturer specific inputs are given in table 6.37.

Table 6.37: Input parameters for manufacturers

Manufacturer number	Batch quantities	Product distribution
1	100	1, 2, 3, 4, 21, 22
2	200	5, 6, 7, 8, 23, 24
3	200	9, 10, 11, 12, 25, 26
4	200	13, 14, 15, 16, 27, 28
5	300	17, 18, 19, 20, 29, 30

The distance matrix between wholesalers and retailers are given in table 6.38.

Table 6.38: Input parameters for wholesalers

	Wholesaler 1 (20)	Wholesaler 2 (30)	Wholesaler 3 (40)	Wholesaler 4 (50)	Wholesaler 5 (50)
Retailer 1	20	20	20	20	20
Retailer 2	30	30	30	30	30
Retailer 3	40	40	40	40	40
Retailer 4	50	50	50	50	50
Retailer 5	60	60	60	60	60
Retailer 6	70	70	70	70	70
Retailer 7	40	40	40	40	40
Retailer 8	40	40	40	40	40

(Distances are in km, Quantities in ( ) indicate velocity of transporters in km/h)

The distance matrix between manufacturers and wholesalers are given in table 6.39.

Table 6.39: Input parameters for wholesalers

	Manufacturer 1 (50)	Manufacturer 2 (60)	Manufacturer 3 (75)	Manufacturer 4 (90)	Manufacturer 5 (100)
Wholesaler 1	40	40	40	40	40
Wholesaler 2	50	50	50	50	50
Wholesaler 3	60	60	60	60	60
Wholesaler 4	50	50	50	50	50
Wholesaler 5	60	60	60	60	60

Distances are in km, Quantities in ( ) indicate velocity of transporters in km/h

6.3.2.5 Results and discussion

The performance measures of the supply chain are shown in table 6.40-6.49. The customer order fill rate in percentage is shown in table 6.40. The number of retailer's stock-outs, number of retail orders satisfied, number of retail order processed and retail order fill rate in percentage are shown in table 6.41-44. The number of wholesale orders processed, number of wholesale backorders, number of wholesale orders satisfied and number of wholesaler fill rate in percentage are shown in table 6.45-6.48. The number of manufacturer stock-outs and number of manufacturer backorders are shown in table 6.49-6.50.

Table 6.40: Customer order fill rate in percentage

Retailer 1									
P1	P4	P9	P12	P14	P18	P22	P25	P28	P29
85	59	58	57	61	56	60	58	82	82
Retailer 2									
P2	P5	P8	P11	P15	P17	P20	P24	P26	P30
59	59	89	62	80	64	87	61	60	64
Retailer 3									
P4	P7	P10	P13	P15	P19	P21	P23	P27	P29
63	59	87	87	78	62	61	85	62	86
Retailer 4									
P3	P6	P8	P11	P14	P17	P22	P25	P28	P30
85	85	83	61	62	59	61	59	83	61
Retailer 5									
P2	P5	P9	P12	P15	P16	P18	P20	P24	P27
65	63	64	63	84	41	63	90	63	64
Retailer 6									
P2	P4	P9	P13	P16	P19	P21	P23	P26	P30
59	61	61	87	40	60	61	64	59	61
Retailer 7									
P1	P5	P7	P11	P14	P17	P19	P22	P24	P27
90	61	61	63	66	61	63	0	61	62
Retailer 8									
P3	P6	P7	P10	P12	P16	P18	P21	P25	P26
92	92	63	92	62	41	62	63	67	63

(P1 stands for product 1; P2 stands for product 2 and like that)

Table 6.41: Number of retailer's stock-outs

Retailer 1									
P1	P4	P9	P12	P14	P18	P22	P25	P28	P29
835	2342	2400	2466	2217	2514	2264	2431	983	986
Retailer 2									
P2	P5	P8	P11	P15	P17	P20	P24	P26	P30
2384	2347	622	2117	1098	2102	736	2243	2276	2040
Retailer 3									
P4	P7	P10	P13	P15	P19	P21	P23	P27	P29
2108	2317	731	708	1228	2167	2179	831	2129	796
Retailer 4									
P3	P6	P8	P11	P14	P17	P22	P25	P28	P30
812	820	940	2174	2167	2342	2224	2240	967	2205
Retailer 5									
P2	P5	P9	P12	P15	P16	P18	P20	P24	P27
1981	2100	1997	2148	857	3393	2109	557	2072	2027
Retailer 6									
P2	P4	P9	P13	P16	P19	P21	P23	P26	P30
2311	2165	2262	685	3413	2213	2207	775	2356	2192
Retailer 7									
P1	P5	P7	P11	P14	P17	P19	P22	P24	P27
556	2223	2174	2047	1891	2198	2046	2062	2225	2164
Retailer 8									
P3	P6	P7	P10	P12	P16	P18	P21	P25	P26
412	416	2102	445	2108	3351	2144	2077	1842	2055

Table 6.42: Number of retail orders satisfied

Wholesaler 1							
P1	P3	P5	P6	P15	-	-	-
188	123	123	123	195	0	0	0
Wholesaler 2							
P2	P4	P8	P10	P12	P13	P18	P20
188	256	119	158	186	223	186	132
Wholesaler 3							
P7	P9	P11	P14	P16	P17	P19	-
140	237	117	166	125	118	189	0
Wholesaler 4							
P21	P25	P26	P29	P30	-	-	-
206	182	198	216	184	0	0	0
Wholesaler 5							
P22	P23	P24	P27	P28	-	-	-
166	222	123	130	179	0	0	0

Table 6.43: Number of retail orders processed

Retailer 1									
P1	P4	P9	P12	P14	P18	P22	P25	P28	P29
138	99	95	94	100	94	100	96	134	136
Retailer 2									
P2	P5	P8	P11	P15	P17	P20	P24	P26	P30
50	50	74	52	67	55	73	51	51	53
Retailer 3									
P4	P7	P10	P13	P15	P19	P21	P23	P27	P29
59	56	82	81	73	58	57	81	57	80
Retailer 4									
P3	P6	P8	P11	P14	P17	P22	P25	P28	P30
46	45	45	33	32	32	33	32	45	33
Retailer 5									
P2	P5	P9	P12	P15	P16	P18	P20	P24	P27
43	42	43	43	56	28	42	59	41	42
Retailer 6									
P2	P4	P9	P13	P16	P19	P21	P23	P26	P30
98	101	102	143	65	99	99	141	97	101
Retailer 7									
P1	P5	P7	P11	P14	P17	P19	P22	P24	P27
50	34	34	35	37	34	35	36	34	34
Retailer 8									
P3	P6	P7	P10	P12	P16	P18	P21	P25	P26
77	78	53	76	52	35	53	53	57	53

Table 6.44: Retail order fill rate in percentage

Wholesaler 1							
P1	P3	P5	P6	P15	-	-	-
100	100	95	100	97	0	0	0
Wholesaler 2							
P2	P4	P8	P10	P12	P13	P18	P20
97	98	100	100	96	100	97	100
Wholesaler 3							
P7	P9	P11	P14	P16	P17	P19	-
98	99	98	98	99	97	98	0
Wholesaler 4							
P21	P25	P26	P29	P30	-	-	-
97	97	97	100	96	0	0	0
Wholesaler 5							
P22	P23	P24	P27	P28	-	-	-
98	100	98	96	100	0	0	0

Table 6.45: Number of wholesale orders processed

Wholesaler 1							
P1	P3	P5	P6	P15	-	-	-
14	14	15	14	20	0	0	0
Wholesaler 2							
P2	P4	P8	P10	P12	P13	P18	P20
15	15	14	15	15	14	15	14
Wholesaler 3							
P7	P9	P11	P14	P16	P17	P19	-
12	12	12	12	8	12	12	0
Wholesaler 4							
P21	P25	P26	P29	P30	-	-	-
15	15	15	14	15	0	0	0
Wholesaler 5							
P22	P23	P24	P27	P28	-	-	-
10	9	10	10	9	0	0	0

Table 6.46: Number of wholesale backorders

Wholesaler 1							
P1	P3	P5	P6	P15	-	-	-
0	0	6	0	6	0	0	0
Wholesaler 2							
P2	P4	P8	P10	P12	P13	P18	P20
6	6	0	0	6	0	6	0
Wholesaler 3							
P7	P9	P11	P14	P16	P17	P19	-
3	3	3	3	0	3	3	0
Wholesaler 4							
P21	P25	P26	P29	P30	-	-	-
6	6	6	0	6	0	0	0
Wholesaler 5							
P22	P23	P24	P27	P28	-	-	-
3	0	3	3	0	0	0	0

Table 6.47: Number of wholesale orders satisfied

Manufacturer 1					
P1	P2	P3	P4	P21	P22
14	14	14	14	14	9
Manufacturer 2					
P5	P6	P7	P8	P23	P24
14	14	11	14	9	9
Manufacturer 3					
P9	P10	P11	P12	P25	P26
11	14	11	14	14	14
Manufacturer 4					
P13	P14	P15	P16	P27	P28
14	11	19	7	9	9
Manufacturer 5					
P17	P18	P19	P20	P29	P30
11	14	11	14	14	14

Table 6.48: Number of wholesaler order fill rate in percentage

Manufacturer 1					
P1	P2	P3	P4	P21	P22
100	88	100	88	88	90
Manufacturer 2					
P5	P6	P7	P8	P23	P24
88	100	92	100	100	90
Manufacturer 3					
P9	P10	P11	P12	P25	P26
92	100	92	88	88	88
Manufacturer 4					
P13	P14	P15	P16	P27	P28
100	92	90	100	90	100
Manufacturer 5					
P17	P18	P19	P20	P29	P30
92	88	92	100	100	88

Table 6.49: Number of manufacturer stock-outs

Manufacturer 1					
P1	P2	P3	P4	P21	P22
0	3	0	3	3	2
Manufacturer 2					
P5	P6	P7	P8	P23	P24
3	0	2	0	0	2
Manufacturer 3					
P9	P10	P11	P12	P25	P26
2	1	2	3	3	3
Manufacturer 4					
P13	P14	P15	P16	P27	P28
0	2	3	1	2	0
Manufacturer 5					
P17	P18	P19	P20	P29	P30
2	3	2	0	0	3

Table 6.50: Number of manufacturer backorders

Manufacturer 1					
P1	P2	P3	P4	P21	P22
0	2	0	2	2	1
Manufacturer 2					
P5	P6	P7	P8	P23	P24
2	0	1	0	0	1
Manufacturer 3					
P9	P10	P11	P12	P25	P26
1	0	1	2	2	2
Manufacturer 4					
P13	P14	P15	P16	P27	P28
0	1	2	0	1	0
Manufacturer 5					
P17	P18	P19	P20	P29	P30
1	2	1	0	0	2

6.4 Conclusions

Today's competitive world, companies are forced to minimize the total system wide cost and optimize the service level. In this chapter, mathematical formulation is developed for a serial three-echelon supply chain for supply chain inventory planning considering the total system wide cost. The mathematical formulation can be implemented through proper sharing of information along the supply chain, because this would make it easy for the decision variables (production quantity at the manufacture, order quantity at the warehouse and retailer and safety factor for manufacture warehouse and retailer) of the supply chain to respond dynamically to any changes in costs, demand, lead-time and etc. The members of the supply chain should change their inventory policies to achieve these objectives. The optimization tool of MATLAB 6.1 is used for supply chain inventory planning. The differential evolution algorithm is also developed supply chain inventory planning. It is found that the results obtained by DE algorithm are better than the results obtained from optimization tool of MATLAB 6.1. The relationship of total system wide cost and safety inventory at different members with maximum average inventory in the serial supply chain is discussed. The simulation model is developed for supply chain inventory planning by using ARENA simulation tool. It is developed for a three echelon serial supply chain (i.e. one manufacturer, one wholesaler and one retailer) that contains all procedures, operations, and flows that occur along a supply chain. Further, several activities that are often found in a real scenario in SCM is considered. The performance measures are so chosen as to aid in the analysis. The optimal operating points of the supply chain are determined as a conclusion of the simulation experiments. This model can be extended to real supply chain which consists of number of suppliers, manufacturers, distributors, retailers and customers. And also simulation model is developed for inventory performance measures by using ARENA simulation tool for a serial supply chain configuration of five manufacturers, five wholesalers and eight retailers for a pool of thirty products. Different inventory performance measures for this supply chain configuration are found out for a given sets input parameters.

References

[1] ARNOLD J. R. T. (1998), Introduction to Materials Management, Prentice Hall, USA.

[2] BABU, B. V., and ANGIRA, R. (2001), "Optimization of Non-linear functions using Evolutionary Computation", *Proceedings of 12th ISME Conference*, Chennai, India, pp. 153-157.

[3] BABU, B. V., and MUNAWAR, S. A. (2000), "Differential Evolution for the optimal design of heat exchangers", *Proceedings of All-India Seminar on*

Chemical Engineering Progress on Resource Development:A Vision 2010 and Beyond, IE (I), Bhubaneswar, India.

[4] BALLOU, R. H., (2004), "Business Logistics/SUPPLY CHAIN MANAGEMENT, Prentice Hall, Upper Saddle River.

[5] CHEN, F. and J. S. SONG, (1997), "Optimal Policies for Multi-Echelon Inventory Problems with Non-stationary Demand," working paper.

[6] CHIOU, J. P. and WANG, F. S. (1999), "Hybrid method of evolutionary algorithms for static and dynamic optimization problems with application to a fed-batch fermentation process", *Computers Chemical Engineering*, vol. 23, pp. 1277-1291.

[7] CHOPRA, S and PETER, M. (2003), Supply Chain Management, Prentice-Hall, New Jersey.

[8] Christopher, M. (1992), Logistic and Supply Chain Management, Pitman Publication, London.

[9] CLARK, A. and SCARF, H. (1960), "Optimal policies for a multi-echelon inventory problem", *Management Science*, vol. 6, pp. 475-490.

[10] DAVID, S.L., KAMINSKY, P. and EDITH, S. L. (2000), Designing and Managing the Supply Chain, Irwin, McGraw-Hill, Boston, MA.

[11] DEB, K. (1996), Optimization for Engineering Design: Algorithms and Examples, PHI, New Delhi.

[12] GANESHAN, R. (1999), "Managing Supply Chain Inventories: a Multiple Retailer, one Warehouse, Multiple Supplier Model", *International Journal of Production Economics*, vol.59, pp.341-354.

[13] GENTRY, J. J. (1996), "The role of carriers in buyer-supplier strategic partnerships: a supply chain management approach", *Journal of Business Logistics*, vol. 17, pp. 33-35.

[14] GLASSMAN, P. and TAYUR, S. (1995), "Sensitivity analysis for base-stock levels in multi-echelon production-inventory systems", *Management Science*, vol. 41, pp. 263-279.

[15] GRAVES, S. C., KLETTER, D. B. and HETZEL, W. B. (1998), "A dynamic model for requirements planning with application to supply chain optimization", *Operations Research*, vol. 46, pp. 35-49.

[16] HARRIS F. W. (1913), "How many parts to make at once, Factory", *The Magazine of Management*, vol. 10, no. 2.

[17] JEFFREY, D., DONG, C., and WUJIN, C. (1998), "Strategic supplier segmentation: the next 'best practice' in supply chain management", *California Management Review*, vol. 40, no. 2, pp. 57-77.

[18] JOSHI, R. and SANDERSON, A. C. (1999), "Minimal representation multi-sensor fusion using differential evolution", *IEEE Transactions on Systems: Man and Cybernetics, Part A*, vol. 29, pp. 63-76.

[19] KELTON, W. D., SADOWSKI, R. P. and SADOWSKI, D. A. (2002), Simulation with Arena, Second edition, McGraw Hill.

[20] LAMMING, R. (1996), "Squaring Lean Supply with Supply Chain Management", *International Journal of Operations and Production Management*, vol.16, no. 2, pp. 183-196.

[21] LAW, A. M. and KELTON, W. D. (2000), Simulation Modeling and Analysis, Third Edition, McGraw Hill.

[22] LEE, H. L. and BILLINGTON, C. (1992) "Managing supply chain inventory: Pitfalls and Opportunities", *Sloan Management Review*, vol. 33, pp. 65–73.

[23] LEE, H. L. and C. BILLINGTON, (1993), "Material Management in Decentralized Supply Chains", *Operations Research*, vol. 41, pp. 835-847.

[24] LEE, M. H., HAN, C. and CHANG, K. S. (1999), "Dynamic optimization of a continuous polymer reactor using a modified differential evolution", *Industrial and Engineering Chemistry Research*, vol. 38, pp. 825-831

[25] MOINZADEH, K., and AGGARWAL, P. K. (1997), "An information based multi-echelon inventory system with emergent orders", *Operations Research*, vol. 45, pp. 694-701.

[26] PRICE, K. and STORN, R. (1997), "Differential evolution", *Dr. Dobb's Journal*, pp. 18-24.

[27] ROBINSON, E. P., GAO, L., and MUGGENBORG, S. D. (1993), "Designing an integrated distribution system at Dow-Brands, Inc.", *Interfaces*, vol. 23, pp. 107-117.

[28] SCHNIEDERJANS, M. J. (1999), International Facility Acquisition and Location Analysis, London: Quorum Books.

[29] SCHRIBER, T. (1991), An Introduction to Simulation using GPSS/H, John Wiley and Sons, New York.

[30] SILVER A.E., PYKE D. F., and PETERSON R. (1998), Inventory Management and Production Planning and Scheduling, Wiley, New York.

[31] STENGER, A. J. (1996), "Reducing inventories in a multi-echelon manufacturing firm: A case study", *International Journal of Production Economics*, vol. 45, pp. 239-249.

[32] STORN R. (1995), "Differential evolution design of an IIR-filter with requirements for magnitude and group delay", *International Computer Science Institute*.

[33] STRADER, T. J., LIN, F. and SHAW, M. J. (1998), "Simulation of order fulfillment in divergent assembly supply chains", *Journal of Artificial Societies and Social Simulation*, vol. 1, no.2.

[34] SWAMINATHAN, J. M., SMITH, S. F. and SADEH, N. M. (1998), "Modeling supply chain dynamics: a multi-agent approach", *Decision Sciences*, vol. 29, no 3, pp. 607-631.

[35] TERSINE, R. J. (1994), Principles of Inventory and Materials Management, Prentice-Hall, Englewood Cliffs.

[36] TOWILL, D. R., NAIM, M. M. and WIKNER, J. (1992), "Industrial dynamics simulation models in the design of supply chains", *International Journal of Physical Distribution and Logistics Management*, vol.22, no.5, pp. 3 – 13.

[37] VISWANATHAN, S. and MATHUR, K. (1997) "Integrating routing and inventory decisions in one-warehouse multi-retailer, multi-product distribution systems", *Management Science*, vol. 43, pp. 294-312.

[38] WANG, F. S. and CHENG, W. M. (1999), "Simultaneous optimization of feeding rate and operation parameters for fed-batch fermentation processes", *Biotechnology Progress*, vol. 15, no 5, pp. 949-952.

[39] WANG, F. S., JING, C. H and TSAO, G. T. (1998), "Fuzzy- decision-making problems of fuel ethanol production using genetically engineered yeast", *Industrial and Engineering Chemistry Research*, vol. 37, pp. 343-443.

[40] ZIMMERMANN, H. J. (2000), "An application-oriented view of modeling uncertainty", *European Journal of Operational Research*, vol. 122, pp. 190–198.

Chapter 7

Design of Supply Chain Network

7.1 Introduction

A supply chain network can be defined as an integrated business process wherein a number of various business entities (i.e. suppliers, manufacturers, distributors, and retailers) work together. For years, researchers and practitioners have primarily investigated the various processes of the supply chain network individually. Recently, however, there has been an increasing attention placed on the performance, design, and analysis of the supply chain network as a whole.

Usually, there are two categories of configuration decisions on supply chain networks:

(i) Structural decisions (long term and strategic issues), which include

- Location of plants and distribution centers
- Number of plants and distribution centers
- Capacity for each facility

(ii) Coordination decisions (short term and operational issues), which include

- Inventory deployment: where and how many
- Centralized or decentralized control for replenishment decisions
- Make-to-stock or make-to-order production policy
- Allocation rules for insufficient stocks.

Decisions regarding the supply chain network design decisions are significant because they determine the amount of flexibility the supply chain has in changing the way it meets demand. These decisions have a long-term impact on a supply chain performance, as it is very expensive. A manger's goal when locating facilities and allocating capacity should be maximized to the overall profitability of the resulting supply chain network from the supplier while providing customers with appropriate responsiveness. Revenues come from the sale of the product and costs arise from facilities, labor, transportation, materials and inventories. The profits of the firm are also impacted by taxes and tariffs. Ideally, profits after tariffs and taxes should be maximized when designing a supply chain network. A manager must consider many trade offs during network design. For example building many facilities to serve local markets reduces transportation cost and provides fast response time, but it increases the facility and inventory costs incurred by the firm. Managers use network design models in two different situations. First, these models are used to decide on locations where facilities will be established and the capacity to be assigned to each facility. Managers must make this decision considering a time horizon over which locations and capacities will not be altered. Second, these models are used to assign current demand to the available facilities and identify lanes along which product will be transported. Managers must consider this decision at least on an annual basis as demand, prices, and tariffs change. In both cases, the goal is to maximize the profit while satisfying customer needs. The following information must be available before the decision can be made:

- Location of supply sources and markets
- Location of potential facility sites
- Demand forecast by market
- Facility, labor, and material costs by site
- Transportation costs between each pair of sites

- Inventory costs by site as well as a function of quantity
- Sale price of product in different regions
- Taxes and tariffs as product is moved between locations
- Desired response time and other service factors

Given this information, network optimization models can be used for design of supply chain network.

7.2 Development of integer programming for the design of supply chain network

One of the optimization techniques that have traditionally received significant attention is the linear programming. Linear Programming (LP) is a mathematical programming technique to optimize performance under a set of resource constraints as specified by an organization. The word linear is used to describe the relationship between the decision variables, which are directly proportional (Jacob 2002, Chandan *et al.*, 1996, Murty 1976, Zeleny 1974, Garvin 1980, Strayer, 1979, Frazer 1968). The word programming means planning activities in a manner that achieves some optimal result with available resources. A program is optimal if it maximizes or minimizes some measure or criterion of effectiveness, such as profit, contribution, sales, cost and etc. (James *et. al.* 1994). Thus linear programming indicates the planning of decision variables, which are directly proportional; to achieve the optimal result considering the limitation within which the problem is to be solved (Ravindran *et al.*, 2000). A linear programming problem is characterized by the following elements:

- An objective function that is a linear function of the decision variables. The objective function is to be maximized or minimized.

- A set of constraints, each of which must be a linear equality or linear inequality in the decision variables.

A sign restriction that specifies for each decision variable either must be nonnegative (greater or equal to zero), or is unrestricted in sign (Murtagh 1981, Gass 1964, Charnes *et al.*, 1961, Vajda 1974, Paul 1964, Rardin 1998). This approach is most useful for linking facilities in a network where supply and demand limitations at plants, distribution center, or market areas must be treated as constraints. Given an objective function that focuses attention on, for example, minimizing total cost, LP defines facility distribution pattern consistent with the problem's demand-supply constraints. The use of integer programming permits the model to deal with issues as fixed and variable costs, capacity constraints and economies of scale (Coyle *et al.*, 2003). A much more general form of the plant location model needs to be considered if entire supply chain network from the supplier to the customer must be designed. A supply chain network is considered in which suppliers send material to plants that supply warehouses that supply markets. Location and capacity allocation decisions have to be made for both plants and warehouses. Multiple warehouses may be used to satisfy demand at a market and multiple plants may be used to replenish warehouses. It is also assumed that units have been appropriately adjusted such that one unit of input from a supply source produces one unit of the finished product. Location and capacity allocation decisions have to be made for both plants and warehouses. It is assumed that multiple warehouses may be used to satisfy demand at a market and multiple plants may be used to replenish warehouses.

The model requires following inputs:

m = Number of markets or demand points

n = Number of potential plant locations

l = Number of suppliers

t = Number of potential warehouse locations

D_j = Annual demand from customer j

S_h = Maximum supply capacity at supplier h

W_e = Maximum warehouse capacity at site e

F_i = Fixed cost of locating a plant at site i

K_i = Maximum capacity at manufacturer i

f_e = Fixed cost of locating a warehouse at site e

c_{hi} = Cost of shipping one unit from supply source h to plant i

c_{ie} = Cost of producing and shipping one unit from plant i to warehouse e

c_{ej} = Cost of shipping one unit from warehouse e to customer j

The goal is to identify plant and warehouse locations as well as quantities shipped between various points that minimize the total fixed and variable costs. Define the following decision variables:

y_i = 1 if plant is located at site i, 0 otherwise

y_e = 1 if warehouse is located at site e, 0 otherwise

x_{ej} = Quantity shipped from warehouse e to market j

x_{ie} = Quantity shipped from plant at site i to warehouse e

x_{hi} = Quantity shipped from supplier h to plant at site

The problem is formulated as the following integer program:

$$Min\sum_{i=1}^{n} F_i y_i + \sum_{e=1}^{t} f_e y_e + \sum_{h=1}^{l}\sum_{i=1}^{n} c_{hi} x_{hi} + \sum_{i=1}^{n}\sum_{e=1}^{t} c_{ie} x_{ie} + \sum_{e=1}^{t}\sum_{j=1}^{m} c_{ej} x_{ej}$$

Subject to (1)

$$\sum_{i=1}^{n} x_{hi} \le S_h \qquad \text{for } h = 1,\ldots,l$$

(2)

$$\sum_{h=1}^{l} x_{hi} - \sum_{e=1}^{t} x_{ie} \ge 0 \qquad \text{for } i = 1,\ldots,n$$

(3)

$$\sum_{e=1}^{t} x_{ie} \le K_i y_i \qquad \text{for } i = 1,\ldots,n$$

(4)

$$\sum_{i=1}^{n} x_{ie} - \sum_{j=1}^{m} x_{ej} \ge 0 \qquad \text{for } e = 1,\ldots,t$$

(5)

$$\sum_{j=1}^{m} x_{ej} \le W_e y_e \qquad \text{for } e = 1,\ldots,t$$

(6)

$$\sum_{e=1}^{t} x_{ej} = D_j \qquad \text{for } e = 1,\ldots,t$$

(7)

$$y_i, y_e \in \{0,1\}$$

The objective function minimizes the total supply chain cost which consists of fixed and transportation cost along with the supply chain network. The constraint in equation 1 specifies that the total amount shipped from a supplier cannot exceed the supplier's capacity. The constraint in equation 2 states that the amount shipped out of a plant cannot exceed the quantity of raw material received. The constraint in equation 3 enforces that the amount produced in the plant cannot exceed its capacity. The constraint in equation 4 specifies that the amount shipped out of a warehouse cannot exceed the quantity received from the plants. The constraint in equation 5 specifies that the amount shipped through a warehouse cannot exceed its capacity. The constraint in equation 6 specifies that the amount shipped to a customer must cover the demand. The constraint in equation 7 enforces that each plant or warehouse is either open or closed.

7.3 Results and discussion

For supply chain network design, 0-1 integer programming is developed and it is solved by using LINDO 6.1. The input parameters for integer programming are given in table 7.1, table 7.2 and table 7.3 for a supply chain configuration of 5*4*10*30 where 5 stands for number of suppliers, 4 stands for number of plants, 10 stands for number of distribution centers and 30 stands for number of demand points. The total supply chain cost is calculated by varying the number of distributors in the supply chain configuration for expected, optimistic and pessimistic demand situation and is shown in the table 7.4, table 7.5 and table 7.6. Figure 7.1 shows the total supply chain cost and number of warehouses for different demand situations and it is found that for nine distribution centers in the supply chain, total supply chain cost is the minimum. Similarly, the total supply chain cost is calculated by varying the number of plants in the supply chain network configuration for expected, optimistic and pessimistic demand situation and are shown in the table 7.7. From the results, it is found that for two plants in the supply chain, total supply chain cost is the minimum. Therefore, the optimum supply chain configuration is 5*2*9*30. For optimum configuration, the total supply chain cost is calculated and shown in the table 7.8. Decision variables which include number of units shipped from suppliers to plants, number of units shipped from plants to warehouses and quantity allocation to demand points for expected, optimistic and pessimistic demand situations are shown table 7.9, table 7.10, table 7.11, table 7.12, table 7.13, table 7.14, table 7.15, table 7.16 and table 7.17 respectively.

Table 7.1: Input parameters for suppliers and plants of SC network 5*4*10*30

Supplier\Plant	1	2	3	4	Maximum capacity of the supplier
1	2	3	4	1	10000
2	3	2	1	4	40000
3	1	3	4	1	50000
4	2	2	1	4	20000
5	3	2	4	3	30000
Maximum capacity of the plant	75000	70000	40000	45000	
Fixed cost of the plant	100000	150000	100000	160000	

Table 7.2: Input parameters for plants and warehouses of SC network 5*4*10*30

Plant\Warehouse	1	2	3	4	5	6	7	8	9	10
1	2	1	0.5	1	2	4	1	2	2.5	0.7
2	3	0.5	1.5	0.5	1	0.5	4	1	1	3
3	1	3	4	1	1	0.6	2	0.5	1.5	2
4	2	3	1	1	1	4	3	0.5	1	2
Maximum capacity of distribution centre	45000	45000	40000	29000	21500	20000	27500	24000	27500	20000
Fixed cost of the distribution centre	10000	15000	5000	4000	9000	4000	6000	4000	8000	6000

Table 7.3: Input parameters for warehouses and demand points of SC network 5*4*10*30

D\W	1	2	3	4	5	6	7	8	9	10	Expected demand	Optimistic demand	Pessimistic demand
1	1	4	4	4	4	2	4	2	3	2	3300	3800	2300
2	4	2	5	2	3	3	5	3	4	3	3600	4100	1600
3	3	3	2	3	5	4	3	4	5	4	2600	3100	2600
4	5	1	1	1	2	3	4	5	2	1	3400	3900	3400
5	3	4	3	1	1	2	2	2	1	2	6300	6800	2300
6	2	5	4	2	3	4	1	2	3	3	2400	2900	2400
7	4	3	4	4	5	1	3	1	4	4	3500	4000	3500
8	2	1	5	5	3	5	2	2	5	5	4500	5000	3000
9	3.5	2	2	3	2	3	1	3	3	4	1300	3800	1300
10	4.5	4	3	4	4	1	3	4	2	3	2400	3800	2400

11	3	3	4	2	5	1	4	3	4	4	3300	3800	3300
12	2	5	5	1	1	2	4	2	3	5	1300	3800	1300
13	5	2	1	4	3	3	2	2	4	2	3425	3925	3425
14	3	1	2	5	2	4	4	3	1	1	2354	2854	2354
15	2	3	3	3	4	2	5	4	3	2	3524	4024	2524
16	2	3	3	3	3	3	3	3	2	2	3215	4515	3215
17	3	1	2	4	4	4	4	4	3	3	2314	3614	2314
18	4	4	4	2	5	2	5	3	1	1	3152	4452	3152
19	2	5	3	3	3	3	4	5	2	2	4521	5821	2521
20	3	3	2	4	4	4	5	4	1	3	3652	5952	3652
21	4	2	3	5	2	3	3	3	2	2	3462	4762	3462
22	1	1	4	1	3	2	2	2	1	3	2365	3665	2365
23	3	3	1	2	1	1	3	3	3	4	3156	4456	3156
24	4	4	2	3	2	3	4	2	1	5	6520	6820	2520
25	5	5	1	4	3	4	3	1	2	3	2365	4665	2000
26	2	3	3	2	2	5	2	2	3	4	3650	4950	2650
27	3	2	1	3	1	3	2	3	4	2	2153	3453	2153
28	4	3	2	4	3	2	3	4	5	1	2315	4615	2315
29	5	1	3	2	4	2	1	2	3	3	3121	5421	2121
30	2	2	2	3	4	3	1	2	2	4	2033	3333	2033

Table 7.4: Total supply chain cost for expected demand situation

Supply chain configuration	Total supply chain cost ($)
5*4*3*30	813495.5
5*4*4*30	790316.5
5*4*5*30	799316.5
5*4*6*30	786454.5
5*4*7*30	789588.0
5*4*8*30	785570.5
5*4*9*30	779638.5
5*4*10*30	783786.5

Table 7.5: Total supply [illegible]

Supply chain configuration	Total supply chain cost ($)
5*4*3*30	937987.5
5*4*4*30	901652.5
5*4*5*30	909866.5
5*4*6*30	885454.5
5*4*7*30	893438.0
5*4*8*30	887220.5
5*4*9*30	876268.5
5*4*10*30	881697.0

Table 7.6: Total supply chain cost for pessimistic demand situation

Supply chain configuration	Total supply chain cost ($)
5*4*3*30	748333.0
5*4*4*30	733654.0
5*4*5*30	742654.0
5*4*6*30	730292.0
5*4*7*30	733425.5
5*4*8*30	732090.5
5*4*9*30	729158.5
5*4*10*30	733306.5

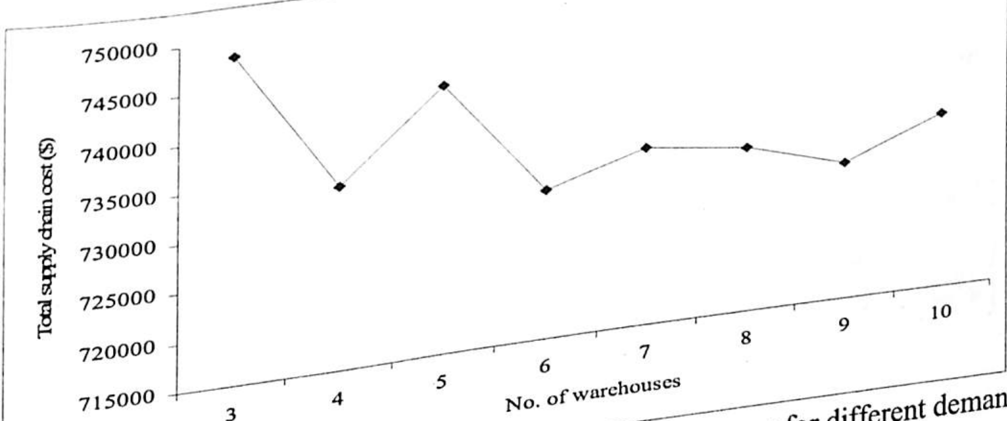


Figure 7.1: Total supply chain cost and number of warehouses for different demand situations

Table 7.7: Total supply chain cost for different number of plants

	Total supply chain cost ($)		
No of plants	Expected demand	Optimistic demand	Pessimistic demand
4	779638.5	876268.5	729158.5
3	714926.0	816826.0	660763.5
2	616576.0	728853.0	561913.5

Table 7.8: Total cost for supply chain configuration 6*2*9*30

Different demand situations	Total supply chain cost
Expected demand	$ 616576.0
Optimistic demand	$ 728853.0
Pessimistic demand	$ 561913.5

from suppliers to

Table 7.7: Total supply chain cost for different number of plants

	Total supply chain cost ($)		
No of plants	Expected demand	Optimistic demand	Pessimistic demand
4	779638.5	876268.5	729158.5
3	714926.0	816826.0	660763.5
2	616576.0	728853.0	561913.5

Table 7.8: Total cost for supply chain configuration 6*2*9*30

Different demand situations	Total supply chain cost
Expected demand	$ 616576.0
Optimistic demand	$ 728853.0
Pessimistic demand	$ 561913.5

Table 7.9: Number of units shipped from suppliers to plants for optimistic demand situation

	Quantity (units)	
Supplier\Plant	1	2
1	10097	9903
2	0	10097
3	50000	0
4	0	20000
5	0	30000

Table 7.10: Number of units shipped from plants to warehouses for optimistic demand situation

	Quantity (units)								
Plant\Warehouse	1	2	3	4	5	6	7	8	9
1	5000	0	24274	25790	4000	0	10033	6820	0
2	0	18076	0	0	0	15424	0	0	20680

Table 7.7: Total supply chain cost for different number of plants

	Total supply chain cost ($)		
No of plants	Expected demand	Optimistic demand	Pessimistic demand
4	779638.5	876268.5	729158.5
3	714926.0	816826.0	660763.5
2	616576.0	728853.0	561913.5

Table 7.8: Total cost for supply chain configuration 6*2*9*30

Different demand situations	Total supply chain cost
Expected demand	$ 616576.0
Optimistic demand	$ 728853.0
Pessimistic demand	$ 561913.5

Table 7.9: Number of units shipped from suppliers to plants for optimistic demand situation

	Quantity (units)	
Supplier\Plant	1	2
1	10097	9903
2	0	10097
3	50000	0
4	0	20000
5	0	30000

Table 7.10: Number of units shipped from plants to warehouses for optimistic demand situation

	Quantity (units)								
Plant\Warehouse	1	2	3	4	5	6	7	8	9
1	5000	0	24274	25790	4000	0	10033	6820	0
2	0	18076	0	0	0	15424	0	0	20680

Table 7.11: Quantity allocation from warehouses to demand points for optimistic demand situation

D\W	1	2	3	4	5	6	7	8	9	Demand
1	0	0	0	0	0	3800	0	0	0	3800
2	0	0	0	4100	0	0	0	0	0	4100
3	0	0	3100	0	0	0	0	0	0	3100
4	0	1425	0	2475	0	0	0	0	0	3900
5	0	0	0	6800	0	0	0	0	0	6800
6	0	0	0	0	0	0	2900	0	0	2900
7	0	0	0	0	4000	0	0	0	0	4000
8	5000	0	0	0	0	0	0	0	0	5000
9	0	0	0	0	0	0	3800	0	0	3800
10	0	0	0	0	0	3800	0	0	0	3800
11	0	0	0	0	0	3800	0	0	0	3800
12	0	0	0	3800	0	0	0	0	0	3800
13	0	0	3925	0	0	0	0	0	0	3925
14	0	2854	0	0	0	0	0	0	0	2854
15	0	0	0	0	0	4024	0	0	0	4024
16	0	0	0	0	0	0	0	0	4515	4515
17	0	3614	0	0	0	0	0	0	0	3614
18	0	0	0	0	0	0	0	0	4452	4452
19	0	0	60	0	0	0	0	0	5761	5821
20	0	0	0	0	0	0	0	0	5952	5952
21	0	4762	0	0	0	0	0	0	0	4762
22	0	0	0	3665	0	0	0	0	0	3665
23	0	0	4456	0	0	0	0	0	0	4456
24	0	0	0	0	0	0	0	6820	0	6820
25	0	0	4665	0	0	0	0	0	0	4665
26	0	0	0	4950	0	0	0	0	0	4950
27	0	0	3453	0	0	0	0	0	0	3453
28	0	0	4615	0	0	0	0	0	0	4615
29	0	5421	0	0	0	0	0	0	0	5421
30	0	0	0	0	0	0	3333	0	0	3333
	5000	18076	24274	25790	4000	19424	10033	6820	20680	130097

Table 7.12: Number of units shipped from suppliers to plants for expected demand situation

Supplier\Plant	Quantity (units)	
	1	2
1	0	20000
2	0	30000
3	25197	0
4	0	20000
5	0	0

Table 7.13: Number of units shipped from plants to warehouses for expected demand situation

Plant\Warehouse	Quantity (units)								
	1	2	3	4	5	6	7	8	9
1	3121	0	12038	7426	6300	0	5733	6520	0
2	0	21995	0	3824	0	12700	0	0	14540

Table 7.14: Quantity allocation from warehouses to demand points for expected demand situation

D\W	1	2	3	4	5	6	7	8	9	Demand
1	0	0	0	0	0	3300	0	0	0	3300
2	0	3600	0	0	0	0	0	0	0	3600
3	0	0	2600	0	0	0	0	0	0	2600
4	0	3400	0	0	0	0	0	0	0	3400
5	0	0	0	0	6300	0	0	0	0	6300
6	0	0	0	0	0	0	2400	0	0	2400
7	0	0	0	0	0	3500	0	0	0	3500
8	0	4500	0	0	0		0	0	0	4500
9	0	0	0	0	0		1300	0	0	1300
10	0	0	0	0	0	2400	0	0	0	2400
11	0	0	0	0	0	3300	0	0	0	3300
12	0	0	0	1300	0	0	0	0	0	1300
13	0	0	3425	0	0	0	0	0	0	3425
14	0	2354	0	0	0	0	0	0	0	2354
15	0	0	0	0	0	3524	0	0	0	3524
16	0	0	0	0	0	0	0	0	3215	3215
17	0	2314	0	0	0	0	0	0	0	2314
18	0	0	0	0	0	0	0	0	3152	3152
19	0	0	0	0	0	0	0	0	4521	4521
20	0	0	0	0	0	0	0	0	3652	3652
21	0	3462	0	0	0	0	0	0	0	3462
22	0	2365	0	0	0	0	0	0	0	2365
23	0	0	0	0	0	3156	0	0	0	3156
24	0	0	0	0	0	0	0	6520	0	6520
25	0	0	2365	0	0	0	0	0	0	2365
26	0	0	0	3650	0	0	0	0	0	3650
27	0	0	2153	0	0	0	0	0	0	2153
28	0	0	1495	0	0	820	0	0	0	2315
29	3121	0	0	0	0	0	0	0	0	3121
30	0	0	0	0	0	0	2033	0	0	2033
	3121	21995	12038	11250	6300	12700	5733	6520	14540	95197

Table 7.15: Number of units shipped from suppliers to plants for pessimistic demand situation

	Quantity (units)	
Supplier\plant	1	2
1	0	20000
2	0	0
3	29526	20474
4	0	7332
5	0	0

Table 7.16: Number of units shipped from plants to warehouses for pessimistic demand situation

	Quantity (units)								
Plant\Warehouse	1	2	3	4	5	6	7	8	9
1	2121	0	10178	13615	3500	0	5733	2520	0
2	0	11130	0	0	0	15995	0	0	12540

Table 7.17: Quantity allocation from warehouses to demand points for pessimistic demand situation

D\W	1	2	3	4	5	6	7	8	9	Demand
1	0	0	0	0	0	2300	0	0	0	2300
2	0	0	0	1600	0	0	0	0	0	1600
3	0	0	2600	0	0	0	0	0	0	2600
4	0	0	0	3400	0	0	0	0	0	3400
5	0	0	0	2300	0	0	0	0	0	2300
6	0	0	0	0	0	0	2400	0	0	2400
7	0	0	0	0	3500	0	0	0	0	3500
8	0	3000	0	0	0	0	0	0	0	3000
9	0	0	0	0	0	0	1300	0	0	1300
10	0	0	0	0	0	2400	0	0	0	2400
11	0	0	0	0	0	3300	0	0	0	3300
12	0	0	0	1300	0	0	0	0	0	1300
13	0	0	3425	0	0	0	0	0	0	3425
14	0	2354	0	0	0	0	0	0	0	2354
15	0	0	0	0	0	2524	0	0	0	2524
16	0	0	0	0	0	0	0	0	3215	3215
17	0	2314	0	0	0	0	0	0	0	2314
18	0	0	0	0	0	0	0	0	3152	3152
19	0	0	0	0	0	0	0	0	2521	2521
20	0	0	0	0	0	0	0	0	3652	3652
21	0	3462	0	0	0	0	0	0	0	3462
22	0	0	0	2365	0	0	0	0	0	2365

23	0	0	0	0	0	3156	0	0	0	3156
24	0	0	0	0	0	0	0	2520	0	2520
25	0	0	2000	0	0	0	0	0	0	2000
26	0	0	0	2650	0	0	0	0	0	2650
27	0	0	2153	0	0	0	0	0	0	2153
28	0	0	0	0	0	2315	0	0	0	2315
29	2121	0	0	0	0	0	0	0	0	2121
30	0	0	0	0	0	0	2033	0	0	2033
	2121	11130	10178	13615	3500	15995	5733	2520	12540	77332

7.4 Conclusions

A 0-1 mixed linear integer programming is developed by using LINDO 6.1 for design of supply chain network. The expected, optimistic and pessimistic demand situations to tackle the uncertain behavior of demand are considered for design of supply chain network. The total supply chain cost is determined for the 5*4*10*30 supply chain network configuration. The total supply chain cost is calculated by varying the number of distributors and plants in the supply chain configuration for expected, optimistic and pessimistic demand situation. It is found that the optimum supply chain configuration is 5*2*9*30. It is a very effective and useful solution approach to design supply chain network.

References

[1] CHANDAN, J., KAWATRA, M., and KIM K. (1996), Essentials of Linear Programming, Vikas Publications, New Delhi.

[2] CHARNES, A. and COOPER W. (1961), Management Models and Industrial Applications of Linear Programming, Wiley Publications, New Jersey.

[3] COYLE, J. J, BARDI, E. J and LANGLEY C. J. (2003), *The Management of Business Logistics*, eight edition, West Publishing, California.

[4] FRAZER, J. (1968), Applied Linear programming, Prentice Hall Publications, Englewood Cliffs, New Jersey.

[5] GARVIN, W. (1980), Introduction to Linear Programming, Prentice Hall Publications, New Jersey.

[6] GASS, S. (1964), Linear Programming and Applications, McGraw Hill Publications, New Jersey.

[7] JACOB, V., NATESAN, T., and UTHAIRAJ, V. (2002), "Analysis of hybrid heuristic model algorithms for solving linear programming problems", *Operation Research Society of India*, vol. 39, no. 3-4, pp. 21-27.

[8] JAMES, I. and CAVALIER, T. (1994), Linear Programming, Prentice Hall Publications, Englewood Cliffs, New Jersey.

[9] MURTAGH, B. (1981), Advanced Linear Programming; Computation and Practice, McGraw-Hill Publications, New Jersey.

[10] MURTY, K. (1976), Linear and Combinatorial Programming, Wiley Publications, New Jersey.

[11] PAUL, L. (1964), Linear Programming; an Introductory Analysis, Tata-McGraw Hill Publications, Bombay.

[12] RARDIN, R. (1998), Optimization in Operations Research, Prentice Hall Publications, New Jersey.

[13] RAVINDRAN, A., PHILLIPS, D., and SOLBERG, J. (2000), Operations Research: Principle and Practice, John Wiley and Sons Publications, Singapore.

[14] STRAYER, J. (1979), Linear Programming and its Applications, Narosa Publications, New Delhi.

[15] VAJDA, S. (1974), Theory of Linear and Non-linear Programming, Longman Publications, London.

[16] ZELENY, M. (1974), Linear Multi-objective programming, S.V. Publications, Berlin.

Chapter 8
Conclusions

In today's highly competitive global market, a company faces exponential degrees of pressure to find new ways to create and deliver value to customers. Over the years, costumer orientation has converted markets into a buyers market. In this market, there is only one boss i.e. the customer. He can fire anybody in the company from chairman down, simply by spending his money somewhere else. This has completely changed the rules in the market. Now companies that used to focus strongly on products are shifting their attention towards customers and their wants. Practically customers no longer want more choices. They want exactly what they want i.e. when, where and how they want it. These new rules of business, combined with maturity of product lines and new sources of global competition, have led to overcapacity in many industries, leading to an inevitable pressure on price. Therefore supply chain management is considered to be core competency. Effective design of the supply chain drivers is nowadays recognized as a key determinant of competitiveness and success for most manufacturing organizations. While many quantitative models have been constructed to provide decision support in different supply chain subsystems, the most pressing challenge to the SCM community is to develop efficient modelling and analysing techniques for supply chain integration and coordination problems so as to gain a full understanding of its characteristics, performance and tradeoffs involved. Without the consideration of integration and component interdependencies, models would lead to non-improving results or just exploit partial benefits. Therefore, it is imperative to employ both analytical and simulation-based techniques, in conjunction with existing methods, to develop model formulations for supply chain design problems. This thesis focuses on four most representative drivers of the supply chain (i.e. facilities, transportation, information and inventory) in supply chain design, providing theoretical and application developments that, in turn, have led to more efficient supply chain designs.

In Chapter 2, the proposed approach provides all the required analyzing methods/techniques for design of supply chain drivers in supply chain management. Prototype decision support systems are proposed for the design of supply chain drivers in supply chain management.

In Chapter 3, decision support systems are developed for design of facilities driver in supply chain management. The facilities driver consists the decisions regrading location, capacity, warehouse methodology and manufacturing systems. Decision support system i.e. performance value analysis model is developed for the selection of facilities location. One case situation is elucidated in order to reinforce the salient features of the concept. Also a decision support system framework is developed for selection of facilities location considering benefit/cost-ratios of the potential feasible locations. The proposed framework is evaluated by a case situation but it can be applicable to different types of industries by allowing managers to structure their unique problems into priority weights, which can reflect their own priority considerations. For capacity decision, decision support system framework is developed which considers both priority of alternative locations and related cost along the supply chain. Simulated annealing algorithm is developed for solving this multi-objective problem. The AHP model is developed for determination of the priority value for alternative locations. The proposed framework is validated by a case situation to reinforce the salient features of the concept. The decision support system framework is developed for selection of warehouse methodology. The framework consists of constant sum model for determination of the priority value for feasible locations, integer programming for optimal number and capacity of warehouses, size of the warehouse and internal warehouse management. One case situation is elucidated in order to reinforce the salient features of the concept. For manufacturing systems, analytical binary model is developed for selection of manufacturing systems and concluded World-class manufacturing systems are better compared to other manufacturing systems. One case situation is elucidated in order to reinforce the salient features of the concept.

In Chapter 4, decision support system framework is developed for design of transportation driver in SCM. The focus is given on selection of transportation mode, route and network, logistics: outsourcing or insourcing and selection of carrier. For selection of mode, a decision support system i.e. ELECTRE III is developed and it is validated by considering a case situation. Detail discussion on core competency has been carried out and it is concluded that for the most of the organisations, logistics does not come under core competency. Therefore logistics should be outsourced. For logistics outsourcing, carrier selection is essential. Hence, decision support system i.e. PROMTHEE II is developed for selection of carrier. The decision support system framework for design of transportation driver is validated with a case situation.

In Chapter 5, a decision support system framework is developed for design of information driver in SCM. The importance of coordination and information sharing, enabling technology and push or pull in supply chain is discussed. The benefits and shortcomings of traditional supply chain, e-supply chain and competitive supply chain are highlighted. A decision support system i.e. relative rating model is developed for justification of the competitive supply chain and importance of forecasting and

Papers Published

[1] Routroy, S. and Kodali, R. (2002), "Useful models for SCM", International Conference on multimedia and design, IIT Mumbai, Track II, pp. 35-49.

[2] Kodali, R. and Routroy, S., (2004) "Analytical hierarchy process for justification of competitive supply chain", The Institution of Engineers (India), vol. 85, pp. 13-17.

Paper accepted

[1] Routroy, S. and Kodali, R. "Differential evolution algorithm for supply chain inventory planning", International Journal of Manufacturing Technology Management (Going to be published in January 2005).

Papers communicated

[1] Kodali, R. and Routroy, S., "Decision framework for selection of facilities location in competitive supply chain", Journal of Advanced Manufacturing Systems (JAMS).

[2] Kodali, R. and Routroy, S., "ELECTRE – III for selection of facilities location in competitive supply chain", The Institution of Engineers (India).

[3] Kodali, R. and Routroy, S., "Relative rating model for justification of competitive supply chain", Productivity.

Papers to be communicated

[1] Kodali, R., and Routroy, S. "Development of decision support systems for transportation decision in supply chain", International Journal of manufacturing technology and management.

[2] Kodali, R. and Routroy, S., "Decision support system for selection of facilities location in competitive supply chain", International Journal of Agile Systems and Management.

[3] Kodali, R., and Routroy, S. "Development of simulation model for inventory planning of a serial supply chain using ARENA 5.0". International Journal of production planning and control.

[4] Routroy, S. and Kodali, R., "A hybrid approach using the analytic hierarchy process and integer programming for capacity decision in the supply chain", IEEE- Engineering Management Journal.

[5] Routroy, S. and Kodali, R., "Development of decision framework for warehouse decisions in competitive supply chain network", International Journal of Logistics Systems and Management.

[6] Routroy, S. and Kodali, R., "Development of decision system for Carrier selection in supply chain", International Journal of Integrated Supply Management.

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