DOKUZ EYLUL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DESIGNING A SUPPLY CHAIN NETWORK FOR AN AUTOMOTIVE COMPANY

by
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İZMİR

DESIGNING A SUPPLY CHAIN NETWORK FOR AN AUTOMOTIVE COMPANY

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"DESIGNING A SUPPLY CHAIN NETWORK FOR AN AUTOMOTIVE COMPANY"** completed by **GAMZE ÖZTUZCU** under supervision of **PROF.DR. SEMRA TUNALI** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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DESIGNING A SUPPLY CHAIN NETWORK
FOR AN AUTOMOTIVE COMPANY

ABSTRACT

An effective supply chain network design involves selecting suppliers, manufacturers and distributors, which all carry out various crucial functions in the order fulfillment process. Effective design and management of supply chain networks (SCN) support to the production and delivery of products at low cost, high quality, high variety and short lead times. In this study, a SCN is designed for a recently introduced product of an automotive company by integrating various approaches. The study has been carried out in two phases: The first phase, which is based on Talluri and Baker’s study (2002), involves selecting suppliers and distributors by using Data Envelopment Analysis (DEA) and integer-programming model. In the second phase, the priority ranking of selected suppliers and distributors are determined by employing the Analytical Hierarchy Process. The optimal quantities and routing of raw materials and finished products are identified by integrating these priority rankings to the relevant transportation models.

Keywords: Supply Chain Management, Data Envelopment Analysis, Integer Programming, Analytical Hierarchy Process, Transportation Problem

BİR OTOMOTİV ŞİRKETİ İÇİN TEDARİK ZİNCİRİ AĞI TASARIMI

ÖZ

Etkin bir tedarik zinciri ağı tasarımı, talep süreçlerini yerine getirmede önemli fonksiyonları yerine getiren tedarikçi, üretici ve dağıtıcıların seçilmesini içerir. Tedarik zinciri ağının etkin tasarım ve yönetimi, ürünlerin daha düşük maliyette, yüksek kalitede, daha fazla çeşitlilikte ve daha kısa tedarik süresinde üretilmesine ve teslim edilmesine destek olmaktadır. Bu çalışmada, bir otomotiv şirketinin piyasaya yakın zamanda çıkardığı ürünü için, çeşitli yaklaşımların biraraya getirilmesiyle bir tedarik zinciri ağı tasarlanmıştır. Çalışma iki fazda gerçekleştirilmiştir: Talluri ve Baker (2002)'in çalışmasına dayanan ilk faz, tedarikçi ve dağıtıcıların Veri Zarflama Analizi ve tam sayılı programlama modelinin kullanılarak seçilmesini içermektedir. İkinci fazda, seçilen tedarikçi ve dağıtıcıların öncelik sıralaması, Analitik Hiyerarşi Süreci uygulanarak belirlenmiştir. Bu öncelik sıralamalarının ilgili taşıma modellerine entegre edilmesiyle de ham madde ve son ürünler için optimal miktar ve rota tanımlanmıştır.

Anahtar sözcükler: Tedarik Zinciri Yönetimi, Veri Zarflama Analizi, Tam Sayılı Programlama, Analitik Hiyerarşi Süreci, Taşıma Problemi

ABBREVIATIONS

Acceptance Rate	AR
Accurately Handled Customer Orders	AHO
Aggregated Mean Efficiency	M_EFF
Analytical Hierarchy Process	AHP
Analytical Network Process	ANP
Artificial Intelligence	AI
Artificial Neural Network	ANN
Asset-Based Logistics	2PL
Banker, Charnes, Cooper	BCC
Capacity Adjustments	CAP ADJ
Capacity	CAP
Case-Based-Reasoning	CBR
Charnes, Cooper, Rhodes	CCR
Cluster Analysis	CA
Consistency Index	CI
Consistency Ratio	CR
Constant Returns-to-Scale	CRS
Coordinated Forecasting And Replenishment	CFAR
Data Envelopment Analysis	DEA
Decision Maker	DM
Decision Making Unit	DMU
Defect Rate	DR
Demand	DEM
Discipline	DISC
Efficiency Measurement System	EMS
Electronic Data Interchange	EDI
Enterprise Resource Planning	ERP
Everyday Low Pricing	EDLP
Experience	EX
Fifth Party Logistics	5PL

Flexibility .... FLEX
Fourth Party Logistics 4PL/FPL
Fuzzy Sets Theory .... FST
Lead Logistics Provider .... LLP
Location Rating .... LOC
Logistics Service Provider .... LSP
Low Cost Cell LCC
Manufacturing Resources Planning .... MRP-II
Material Requirements Planning .... MRP
Mathematical Programming .... MP
Modified Distribution Method .... MODI
Most Productive Scale Size .... MPSS
North West Corner. .... NWC
On-Time Delivery .... OTD
Operating Cost Per Dollar Revenue .... OC
Pair-wise Efficiency Game .... PEG
Procedural Compliance .... PRO COMP
Quality .... QLTY
Random Index .... RI
Reliability .... REL
Service Level .... SL
Special Requests .... SPEC REQ
Supply Chain Management .... SCM
Supply Chain Network .... SCN
Supply Chain .... SC
Third Party Logistics 3PL/TPL
Total Cost of Ownership .... TCO
Total Cost .... TC
Variable Returns-to-Scale .... VRS
Vendor Managed Inventory .... VMI
Visual Interactive Goal Programming .... VIG
Vogel's Approximation Method .... VAM

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CHAPTER ONE
INTRODUCTION

1.1 Supply Chain Network Design

Competition has imposed pressure on product and service providers to emphasize short delivery lead times, flexibility, low cost and high quality. Companies are responding to this pressure in various ways: One such strategy utilized by the companies is to integrate purchasing and supply management with other key business functions such as production, distribution and finance.

In recent years, to gain competitive advantage, the companies have placed considerable emphasis on supply chain networks (SCNs). SCNs are considered as a solution for effectively meeting customer requirements such as low costs, high product variety, high quality, and short lead times (Busby and Fan, 1993; Byrne, 1993; Goldman, 1994; Iacocca Institute, 1991; Johnston and Lawrence, 1988; Snow et al., 1992). The success of SCNs depends to a large extent on how effectively they are designed and operated. While network design involves the selection of suppliers and distributors, network operation includes exact sourcing and deployment plans.

There are many strategic, tactical, and operational aspects that must be considered in designing and operating SCNs. Strategic issues in supply chain network design are anticipatory, i.e. they best prepare the supply chain to meet risk and uncertainty. Strategic issues are related to supplier and distributor selection, facility location, production and inventory decisions. The operational issues in supply chain network design focus on activities over a day-to-day basis. They involve activities like production planning, emergency measures, production scheduling in different production sites, storage scheduling within warehouses etc.

This thesis primarily focuses on strategic issues in SCN design including supplier and distributor selection and also some operational issues that involve sourcing and deployment plans.

In this thesis, a SCN is designed for a recently introduced product of an automotive company by integrating various approaches. The study has been carried out in two phases: The first phase, which is based on Talluri and Baker's study (2002), involves selecting suppliers and distributors by using Data Envelopment Analysis (DEA) and integer-programming model. It must be noted that addressing a real industrial problem in this study, the suppliers and distributors were selected for a given number of manufacturers. Following, we employed transportation models to identify the optimal quantity and routing decisions for supply of raw materials and distribution of finished products. Moreover, to reflect the preferences of the company on selected suppliers and distributors, we calculated a priority ranking for each using Analytical Hierarchy Process (AHP) and integrated these rankings into the transportation models.

1.2 Thesis Outline

The thesis is organized as follows:

Chapter One contains a brief description of the SCN design and describes the scopes of the study.

Chapter Two concerns definition of Supply Chain Management (SCM), key issues in SCM, SCM decisions, SCN structure and also supplier evaluation and selection in detail.

Chapter Three presents the approaches used for supplier and distributor selection such as linear weighting models, total cost of ownership models, mathematical programming models, statistical models and artificial intelligence based models.

Chapter Four explains DEA and AHP in detail. In this thesis, DEA is utilized to select the suppliers and distributors that take place in the SCN. AHP is utilized to take into consideration the preferences of the company in giving optimal quantity and routing decisions.

Chapter Five presents the transportation and transshipment problems in detail. In this thesis, sourcing and deployment plans for raw materials and also finished products are constituted by solving transportation problems.

Chapter Six suggests a methodology for an effective SCN design under the demand and capacity constraints and discusses the steps of each stage of the procedure in detail. Following, a SCN is developed for a recently introduced product of an automotive company by using the suggested systematic procedure.

Chapter Seven summarizes the findings of this study and states the future research directions.

CHAPTER TWO
SUPPLY CHAIN MANAGEMENT

2.1. Introduction

Traditional concepts and methods for business management focused on the optimization of the internal activities in a company. Examples of such methods are Flexible Manufacturing Systems, Material Requirement Planning, Material Resource Planning and so on. These methods faced a limit on the degree to which they can improve a given business system.

In today's competitive global markets, no business can be successful without mastering the issues, problems and possibilities in managing supply chains (SC). Forward-thinking managers must employ new technological and quantitative tools to devise an integrated approach to managing their entire business, including procurement, inventory, manufacturing, logistics, distribution and sales. This broad, comprehensive approach is known as Supply Chain Management (SCM). SCM implies the optimization of the whole process from suppliers to end customers.

SCM is the term used to describe the management of the flow of materials, information, and funds across the entire supply chain, from direct suppliers to its direct customers including purchasing, warehousing, inspection, production, material handling, shipping and distribution. In fact, it often includes after-sales service and returns or recycling. In contrast to multi-echelon inventory management, which coordinates inventories at multiple locations, SCM typically involves coordination of information and materials among multiple firms.

SCM has generated much interest in recent years for a number of reasons. Many managers now realize that actions taken by one member of the chain can influence the profitability of all others in the chain. Firms are increasingly thinking in terms of competing as part of a supply chain against other supply chains, rather than as a single firm against other individual firms. Also, as firms successfully streamline their own operations, the next opportunity for improvement is through better coordination with their suppliers and customers.

This chapter is structured as follows: Section 2.2 explains the term supply chain, Section 2.3 defines SCM and gives a brief history of SCM. Section 2.4 discusses some important issues in SCM. Section 2.5 presents the decisions involved in SCM. Section 2.6 involves supply chain modeling approaches. Section 2.7 gives brief information about supply chain network structure. And finally section 2.8 defines supplier evaluation and selection.

2.2. The Supply Chain

Today, ever increasing technical complexity of standard consumer goods, combined with the ever increasing size and depth of the global market has meant that the link between consumer and supplier is usually only the final link in a long and complex chain or network of exchanges. The supply chain begins with the extraction of raw material, includes several production links, for instance component construction, assembly and merging before moving onto several layers of storage facilities of ever decreasing size and ever more remote geographical locations, and finally reaching the consumer. Harold Sirkin stated that “As the economy changes, as competition becomes more global, it’s no longer company vs. company but supply chain vs. supply chain”.

A simple example of a supply chain is shown in Figure 2.1. In this simple example, material flows from the left side to the right side. The material flow is from the suppliers, who provide materials and subassemblies, to the manufacturers, who build, assemble, convert, or furnish a product or service. The finished products then pass to distributors, who transport and deliver the finished product to the customers. While material flows from left to right, that is from suppliers to manufacturers, distributors and customers, information flow in a conventional supply chain can be considered to flow in the opposite direction. The customers order from the distributors, who then order from the manufacturers and so on down through the supply chain, from right to left in Figure 2.1 (O'Grady, 2003).

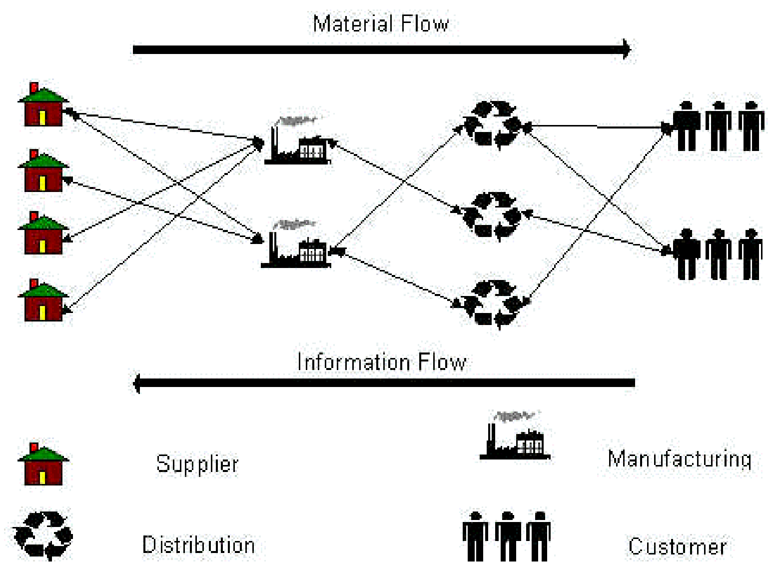


Figure 2.1 A supply chain (O'Grady, 2003)

There seems to be a universal agreement on what a supply chain is. Ganeshan & Harrison (1995) has stated that: "A supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers".

Likewise, Christopher (1998) presented that a SC is a 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 for the ultimate consumer. This definition stresses that all the activities along a SC should be designed according to the needs of the customers to be served. Consequently, the (ultimate) consumer is at best an integral part of a SC. The main focus is on the order fulfilment process(es) and corresponding material, financial and information flows.

In a recent study, Monczka & Trent (2002) defined the scope of supply chain as all activities associated with the flows and transformation of goods from the raw materials stage (extraction), through to end users, as well as the associated information flows. It must be noted that in a SC, material and information flow both up and down. The supply chain includes systems management, operations and assembly, purchasing, production scheduling, order processing, inventory management, transportation, warehousing, and the customer is in turn a supplier to the next downstream organization until a finished product reaches the ultimate user.

In traditional supply chains, the marketing, distribution, planning, manufacturing and purchasing organizations along the supply chain operate independently (Ganeshan & Harrison, 1995). Individual organizations often have their own objectives that can often conflict. Consequently, there is not a single, unified plan or set of objectives for the organization. These can cause a complexity in the supply chain. This complexity can be caused by several another factors:

- The large mesh of interlinked suppliers, manufacturers and distributors.
- The fact that each participant (supplier, manufacturer and distributor) may be a member of a large number of other supply chains.
- The dynamic nature of the supply chain (O'Grady, 2003).

The result of the complexity can be an excessive time taken to respond to changes in customer demand. The difficulties imposed by the complexity are compounded by the increase in competitive pressure with the demand for greater levels of responsiveness and shorter cycle times.

In spite of the inherent complexity, there is considerable pressure to improve coordination in supply chains. What is giving added urgency are the recent developments in communications. These developments are primarily based on Internet technologies, that offer the promise of connecting suppliers, assemblers and customers in a seamless network of information (Wu & O'Grady, 2005). In such an integrated supply chain management structure, each entity can have visibility of other portions of the supply chain, thereby allowing for the potential for improved decision making and, hence, for reduced costs and reduced response time (Andersen et al., 1986).

2.3. The Supply Chain Management

Supply Chain Management is the planning and execution of supply chain activities, ensuring a coordinated flow within the enterprise and among integrated companies. These activities include the sourcing of raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels and, ultimately, delivery to the customer. The primary objectives of SCM are to reduce supply costs, improve product margins, increase manufacturing throughput, and improve return on investment (Mayer, 2001).

The basic idea behind the SCM is that companies and corporations involved in a supply chain by exchanging information regarding market fluctuations, production capabilities etc. can rationalize the processes involved in the supply chain resulting in mutual gains. If all relevant information is accessible to any relevant company, every company in the supply chain has the possibility to and can seek to help optimizing the entire supply chain rather than sub optimize based on a local interest. This will lead to better planned overall production and distribution which can cut costs and give a more attractive final product leading to better sales and better overall results for the companies involved.

Historically, companies have focused on their own organisation with the aim to increase their profits. They saw themselves as one single company “fighting” against other companies to increase their market shares and profitability. In order to survive, companies had to compete against each other; however, this focus is now changing and it is common to hear about supply chains competing with each other (Christopher, 1998).

The successful creation of a working SCM is also a very complex affair which raises many questions and involves a number of challenges. Much work has been done on mapping the term SCM and defining how to incorporate SCM and how to successfully overcome the inevitable problems encountered, but because of the obvious vastness of the problem many has different approaches and ways of considering the problem be pointed out.

Several definitions of SCM appear on the literature. Simchi-Levi et al. (2000) stated that: “Supply Chain Management is a set of approaches utilized to efficiently integrate suppliers, manufactures, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements.”

Jones & Riley (1985) defined SCM as “an integrated approach to dealing with the planning and control of the material flow from suppliers to end users”. This leads on to supply chain integration. Supply chain integration is defined by Boorsma & Van Noord (1992) as the “coordination of logistical activities between separate links in the chain in order to plan, control and execute the logistics processes as one integrated system and the aim of improving the logistics performance of the complete system.”

2.3.1. Brief History of Supply Chain Management

The post-World War II supply chain was a set of linear, individualized processes that linked manufacturers, warehouses, wholesalers, retailers and consumers together in the form of a human/paper chain. "People and paper physically connected all of the tiers of the chain together," which often created miscommunication between the front- and back-end processes (Mayer, 2001). The synching of procurement, demand planning and forecasting, inventory management, shipping and tracking were far from a definitive science. However, as manufacturing and economic growth flourished during the 1950s, there developed a greater interest in the need for SCM.

The 1960s saw the birth of the first inventory management software systems, which were typically customized, to aid inventory control in the manufacturing sector. In the 1970s, SCM innovations brought forth Material Requirements Planning (MRP) – a system that phases out the release of production and purchase orders to ensure that the flow of raw materials and in-process inventories matches the manufacturer's production schedules for finished products. By the 1980s, Manufacturing Resources Planning (MRP-II) was developed, bringing with the systems that could be used for planning all manufacturing resources, including those related to operational planning, financial planning, business planning, capacity requirements planning, and master production scheduling. It was MRP-II's extension into the business enterprise that evolved into an entirely new information technology sector: Enterprise Resource Planning (ERP) (Mills & Blaine, 2001).

In 1988, SCM took a significant leap of its own. Sanjiv Sidhu, founder of Dallas, Texas-based i2 Technologies and a former artificial intelligence expert with Texas Instruments, developed a new breed of software that was based upon the "theory of constraints". Sidhu's product would allow a "company's factories (to) communicate internally, with each other, and with headquarters to improve the flow of materials and orders". By 1997, this software had become Internet-enabled. Other firms have developed expertise in either specific industries, such as consumer goods and process industries, or very specific niches of the supply chain, such as execution and tracking (Mount & Caulfeld, 2001).

SCM has taken on additional names, such as business-to-business or B2B. It's processes and capabilities have also allowed for more focused, "one-on-one" extensions – namely exchanges. An exchange is a two-sided marketplace where buyers and suppliers negotiate prices and fulfill online transactions between one another and are either private or public. For example, a private exchange would involve Company A selling widgets to Company B, meeting together on a secure web site to place and fulfill orders exclusively and by invitation only; a public exchange is more of an auction or bidding place for pre-qualified subscribers or members (Electronics Industry Data Exchange Association, 2004).

2.4. Key Issues in Supply Chain Management

Supply chain management is an enormous topic covering multiple disciplines and employing many quantitative and qualitative tools.

Supply chain management is divided into twelve areas and each of them is examined in detail in the following sections (Johnson & Pyke, 2000). Each area represents a supply chain issue facing the firm. For any particular problem or issue, managers may apply various decision support tools. The twelve categories are:

- Facility Location and Network Design
- Transportation and Logistics
- Inventory and Forecasting
- Marketing and Channel Restructuring
- Sourcing and Supplier Management
- Information and Electronic Mediated Environments
- Product Design and New Product Introduction
- Service and After Sales Support
- Reverse Logistics and Green Issues
- Outsourcing and Strategic Alliances
- Metrics and Incentives
- Global Issues.

*2.4.1. **Facility Location And Network Design***

Facility location and network design pertain to both qualitative and quantitative aspects of facility location decisions. This includes models of facility location, geographic information systems, country differences, taxes and duties, transportation costs associated with certain locations, and government incentives (Hammond & Kelly, 1990). Exchange rate issues fall in this category, as do economies and diseconomies of scale and scope. Decisions at this level set the physical structure of the supply chain and therefore establish constraints for more tactical decisions. Binary integer-programming models play an important role here, as do simple spreadsheet models and qualitative analyses.

It seems that some of the models dedicated to location issues in the literature are quite simple when representing real problems in the design of an actual supply chain. For example, in a warehouse location problem, the authors do not take in account the warehouse capacity, the warehouse handling and operational costs (most of then just take in account the warehouse fixed initial cost) or the warehouse service level requirements. Also, when designing a supply chain that involves several countries, the issues such as import and export taxes, different transportation options, cultural and legal issues must be taken into consideration. The incorporation of these aspects in the model can make a significant difference on the analysis of the SC network.

2.4.2. ***Transportation And Logistics***

Transportation and logistics activities have a major impact on the capabilities and profitability of a supply chain and its member firms. This category encompasses all issues related to the flow of goods through the supply chain, including:

- transportation and vehicle routing,
- warehouse management and distribution strategies,
- material handling and order picking.

Both deterministic (such as linear programming and the travelling salesman problem) and stochastic optimization models (stochastic routing and transportation models with queuing) often are used here, as are spreadsheet models and qualitative analysis. Greis & Kasarda (1997) examined the changes within the logistics functions of many firms as a result of functional integration and Fuller et al. (1993) examined the role of logistics in gaining competitive advantage.

2.4.2.1. Transportation And Vehicle Routing

One of the central problems of SCM is the coordination of product and material flows between the members of SC. A typical problem involves bringing products located at a central facility to geographically dispersed facilities at minimum cost. For example, a supply of product is located at a plant, warehouse, cross-docking facility or distribution center and must be distributed to customers or retailers. The task is often performed by a fleet of vehicles under direct control of the firm.

Transportation is an area that absorbs a significant amount of the cost in most firms. Therefore, methods for dealing with the important issues in transportation such as mode selection, carrier routing, vehicle scheduling and shipment consolidations are of need in most companies. One important aspect in transportation management is the coordination with the remaining activities in the firm, especially within warehouse and customer service. In some cases the transport is the last contact with the customer, and therefore, the companies pay attention to fulfill the customer expectations and use this relationship to improve their sales. The transport coordination of the different elements of a supply chain, that can evolve different companies, can be very important since all of the elements of a supply chain most likely benefit by having a fast delivery to a specific customer. Therefore, many issues in the integration of transportation with other activities in the network can be a challenge to the academic and industrial communities. One basic and well-known problem in transportation is the vehicle scheduling and routing. A vehicle scheduling system should output a set of instructions telling drivers what to deliver, when and where. An “efficient” solution is one that enables goods to be delivered when and where they are required at least cost, subject to legal and political constraints (Lourenço, 2002).

2.4.2.2. Warehouse Management And Distribution Strategies

Warehousing is an integral part of every logistics system and plays a vital role in providing a desired level of customer service. Warehousing can be defined as a part of a supply chain that stores products (raw materials, parts, work-in-process and finished goods) at and between points of production and points of consumption, and provides information to management on the status and disposition of items being stored. The basic operations on a warehouse are receiving, storage-handling, order picking, consolidation – sorting and shipping. The main objectives are to minimize the product handling and movement and store operations as well as maximize the flexibility of the operations. But traditional warehouses are suffering enormous transformations by the introduction of direct shipment and cross-docking strategies. These last strategies may be more effective in distributing the products among the retailer or customer. However, to be successful, these strategies require high coordination and information systems integration between all elements on the supply chain. Deciding which distribution strategy of a particular product of a company is best can make an enormous impact on the company success. Therefore, there is a need for decision support systems that help executive managers to select the best distribution strategies at the warehouse level (Lourenço, 2002).

2.4.2.3. Material Handling And Order Picking

Material handling is a broad area that encompasses basically all activities related with the movement of raw material, work in process, or finished goods within a plant or warehouse. Moving a product within a warehouse is a no value-added activity but incurs in a cost. Order processing or picking includes basically the filling of a customer order and making it available to the customer. These activities can be quite important since they have impact on the time that it takes to process customer orders in the distribution channel or to make supplies available to the production function. They are cost absorbing and need attention from the managers. Packaging is valuable both as a form of advertising and marketing and also for protection and storage from a logistical perspective. Packaging can ease movements and storage by being properly designed for the warehouse configuration and material handling equipment. The major decisions in this area include facility configuration, space layout, dock design, material-handling systems selection, stock locator and arrangement, equipment replacement, and order-picking operations (Lourenço, 2002).

2.4.3. ***Inventory And Forecasting***

Inventory and forecasting include traditional inventory and forecasting models. Inventory costs are some of the easiest to identify and reduce when attacking supply chain problems. Simple stochastic inventory models can identify the potential cost savings from, for example, sharing information with supply chain partners, but more complex models are required to coordinate multiple locations (Lee & Nahmias, 1993).

Supply chains confront the problem of multiple firms, each with its own decision-maker and objectives. In nearly every case, multi-echelon inventory models assume a single decision-maker. Clark & Scarf (1960) performed one of the earliest studies in serial systems with probabilistic demand. They introduce the concept of an imputed penalty cost, wherein a shortage at a higher echelon generates an additional cost. This cost enables us to decompose the multi-echelon system into a series of stages so that, assuming centralized control and the availability of global information, the ordering policies can be optimized. Lee & Whang (1999) and Chen (1996) both proposed performance measurement schemes for individual managers that allow for decentralized control, and in certain instances, local information only. The result is a solution that achieves the same optimal solution.

Most of the models well known in the literature are simple and, for example, do not consider multi-product inventory management that require the same resources, or in some case do not treat all the complexities involved in inventory management such as the demand uncertainty. Also, so far the most well known inventory models and systems consider a single facility managing its inventories in order to minimize its own costs. One important challenge in SCM is to manage inventory in the whole supply chain while minimizing the system-wide cost. This requires models and decision support systems that are able to help decisions and suggest policies for the inventory management in the whole supply chain (Lourenço, 2002).

Supply chain sales forecasting management can significantly influence operating performance within each member, and across members, of a supply chain. To affect supply chain operations in a positive manner, organizations working together in a supply chain must improve forecasting management performance (an internally directed measure) as well as supply chain forecasting management performance (a cross-company measure).

To understand the overall supply chain demand-planning process and influence the behaviors of individuals and organizations involved in the development and application of sales forecasts, supply chain managers must go beyond traditional measures of forecast accuracy.

2.4.4. ***Marketing And Channel Restructuring***

Marketing and channel restructuring includes fundamental thinking on supply chain structure and covers the interface with marketing that emerges from having to deal with downstream customers (Narus & Anderson, 1996). While the inventory category addresses the quantitative side of these relationships, this category covers relationship management, negotiations, and even the legal dimension. Most importantly, it examines the role of channel management and supply chain structure in light of the bullwhip effect (Andersen, Day & Rangon, 1997).

Because of trade promotions, volume discounts, long lead times, full-truckload discounts, and end-of-quarter sales incentives, the orders seen at the manufacturers are highly variable (Hammond, 1994). In fact, the variability increases in moving up the supply chain from consumer to grocery store to distribution center to central warehouse to factory, a phenomenon that is often called the bullwhip effect. The costs of this variability are high - inefficient use of production and warehouse resources, high transportation costs, and high inventory costs (Johnson & Pyke, 1999).

The bullwhip effect has received enormous attention in the literature. It is noted that central warehouses are designed to buffer the factory from variability in retail orders. The inventory held in these warehouses should allow factories to smooth production while meeting variable customer demand. However, empirical data suggests that exactly the opposite happens. Orders seen at the higher levels of the supply chain exhibit more variability than those at levels closer to the customer. In other words, the bullwhip effect is real. Lee et al. (1997) showed how four rational factors help to create the bullwhip effect:

1. Demand signal processing; if demand increases, firms order more in anticipation of further increases, thereby communicating an artificially high level of demand;
2. The rationing game (there is, or might be, a shortage so a firm orders more than the actual forecast in the hope of receiving a larger share of the items in short supply);
3. Order batching, fixed costs at one location lead to batching of orders;
4. Manufacturer price variations, which encourage bulk orders.

The latter two factors generate large orders that are followed by small orders, which implies increased variability at upstream locations.

Some recent innovations, such as increased communication about consumer demand, via electronic data interchange (EDI) and the Internet, and everyday low pricing (EDLP) (to eliminate forward buying of bulk orders), can mitigate the bullwhip effect. Bell et. al. (1998a and 1998b) discussed of EDLP versus High-Low pricing. They show with a simple model that High-Low pricers can charge a higher average price without risking the loss of rational customers.

In addition, Baganha & Cohen (1998) noted that, if locations that are designed to buffer the factory from variability in retail orders follow the optimal policy, the variance can in fact be reduced. In particular, these locations should account for auto-correlation in the demand process; that is, if a retailer orders today, it is unlikely that it will order in the next few days.

In fact, the number of firms ordering, and receiving orders, via EDI and the Internet is exploding. The information available to supply chain partners, and the speed with which it is available, has the potential to radically reduce inventories and increase customer service.

Other initiatives can also mitigate the bullwhip effect. For example, changes in pricing and trade promotions and channel initiatives, such as vendor managed inventory (VMI), coordinated forecasting and replenishment (CFAR), and continuous replenishment can significantly reduce demand variance. Vendor Managed Inventory is one of the most widely discussed partnering initiatives for improving multi-firm supply chain efficiency.

In a VMI partnership, the supplier—usually the manufacturer but sometimes a reseller or distributor—makes the main inventory replenishment decisions for the consuming organization. This means the supplier monitors the buyer’s inventory levels (physically or via electronic messaging) and makes periodic re-supply decisions regarding order quantities, shipping, and timing. Transactions customarily initiated by the buyer (like purchase orders) are initiated by the supplier instead. Indeed, the purchase order acknowledgment from the supplier may be the first indication that a transaction is taking place; an advance shipping notice informs the buyer of materials in transit. Thus the manufacturer is responsible for both its own inventory and the inventory stored at is customers’ distribution centers.

Because many of these initiatives involve channel partnerships and distribution agreements, this category also contains important information on pricing, along with anti-trust and other legal issues. These innovations require inter-firm, and often intra-firm, cooperation and coordination that can be difficult to achieve (Johnson & Pyke, 1999).

2.4.5. Sourcing And Supplier Management

While marketing focuses downstream in the supply chain, sourcing and supplier management focuses upstream. This category plays a critical, boundary-spanning role in the supply chain management activities of a firm. In order to achieve the potential benefits of SCM, the role of purchasing must be viewed in a system-wide context, and must be focused beyond managing the buyer-seller relationship.

The location category addresses the location of a firm's own facilities, while this category pertains to the location of the firm's suppliers. Supplier relationship management and make/buy decisions fall into this category as well (Womack, Jones & Roos, 1991).

It is important for managers to understand the potential benefits, as well as the costs, of developing such relationships so that appropriate business decisions can be made. Cost and quality improvements must be understood and implemented from a system-wide perspective to achieve optimum results.

The desired outcome of supplier management is a win-win relationship, where both parties benefit. Long-term strategic alliances are developed with a small core group of suppliers. This is a change from the traditional bid-and-buy system to involving a key supplier early in the design cycle, which can lead to dramatic reduction in product development cycle times. Suppliers are categorized based on several dimensions, such as their contribution and criticality to the organization. Having early supplier input reduces time by getting the required coordination between engineering, purchasing, and the supplier prior to design finalization. And also determining the number of suppliers and the best way to structure supplier relationships are becoming an important topics in supply chains (Lambert & Cooper, 2000).

The supplier management function develops rapid communication mechanisms such as electronic data interchange (EDI) and Internet linkages to quickly transfer requirements. These rapid communication tools provide a means to reduce time and cost spent on the transaction portion of the purchase. Purchasers can focus their efforts on managing suppliers as opposed to placing orders and expediting. This also has implications for the role of the sales force when orders are not placed through the sales person.

2.4.6. Information And Electronic Mediated Environments

As the business environment continues to emphasize more variety and quicker response to a dynamic customer driven marketplace, better and more effective information systems need to be developed. The information and electronic mediated environments category addresses long-standing applications of information technology to reduce inventory and the rapidly expanding area of electronic commerce. Often this subject may take a more systems orientation, examining the role of systems science and information within a supply chain (Senge, 1990). Such a discussion naturally focuses attention on integrative ERP software such as SAP, Baan and Oracle, as well as supply chain offerings such as i2's Rhythm and Peoplesoft's Red Pepper. The many supply chain changes created by electronic commerce are particularly interesting to examine, including both the highly publicized retail channel changes and the more substantial business to business innovations.

Computer and information technology has been utilized to support logistics for many years. Information technology is seen as the key factor that will affect the growth and development of logistics (Tilanus, 1997). It is the most important factor in an integrated supply chain, also playing an important role in the executive decision-making process. More sophisticated applications of information technology such as decision support systems based on expert systems, simulation and metaheuristics systems are applied directly to support decision making on SCM. A decision support system incorporates information from the organization's database into an analytical framework with the objective of easing and improving the decision making. A critical element on a decision support system for logistics decision is the quality of the data used as input of the systems. Therefore, in any implementation, efforts should be made to have accurate data. Afterwards, the modeling and techniques applied to obtain a scenario or analysis of a logistics situation should be adapted to the environment of the company and support the decision processes.

2.4.7. Product Design And New Product Introduction

If new products are the lifeblood of a corporation, then Product design and new product introduction is the lifeblood of a company's new products. This category deals with design issues for mass customization, delayed differentiation, modularity and other issues for new product introduction.

The characteristics of the product, as the weight, volume, parts, value, perishability, etc., influence the decisions on a supply chain, since the need for warehousing, transportation, material handling and order processing depend on these attributes. Products designed for efficient packaging and storage obviously make an impact on the flow in the supply chain and cost less to transport and store. During the design process of a new product, or changes on an existing one, the requirements of the logistics related to the product movements should be taken into consideration. Also, the need for short lead times and the increased request by customer to unique and personalized products put pressure on efficient product design, production and distribution. Postponement is one successful technique that can be applied to delay product differentiation and also lead to an improvement on the logistics of the product (Lee et al., 1993). The use of information systems and simulation technique that help to analyze the impact on the supply chain of a certain design of a specific product can be or great help to the managers.

Customers and suppliers must be integrated into the product development in order to reduce time to market. As product life cycles shorten, the right products must be developed and successfully launched in ever-shorter timeframes in order to remain competitive.

2.4.8. The Service And After Sales Support

The service and after sales support category addresses the critical, but often overlooked, problem of providing service and service parts (Cohen & Lee, 1990). Stochastic inventory models for slow-moving items fall into this category. While industry practice still shows much room for improvement, several well-known firms have shown how spare parts can be managed more effectively.

The service and after sales support is often cited as a key objective of supply chain management. However, only if service offerings create value for customers will they lead to behaviors that improve supply chain performance. To achieve this objective, it is important for supply chain managers to manage the service and after sales support strategically and develop supply chain capabilities to deliver services viewed as important by critical downstream customers.

Being able to fulfill the customer expectations is a task of the SCM, and deciding the level of the service and after sales support to offer customers is essential to meeting a firm’s profit objective. The service and after sales support is a broad term that may include many elements ranging from product availability to after-sales maintenance. In brief, it can be seen as the output of all logistics activities that also interact with other functions in the firm especially with marketing. Since all the elements of the supply chain interact and a decision on one element affects the other ones, then any supply chain decision can affect the customer service. Therefore, system-wide decision support systems that help the decision maker at strategic, tactic and operation level, to evaluate, simulate and analyze different options and scenarios, and the interaction between the players in a supply chain are of increased request by the many companies. The problems in general are complex and the decision-maker will benefit from a decision support system that can generate several scenarios and what-if analysis in short time, and analyze the impact of one decision on the whole system (Lourenço, 2002).

2.4.9. Reverse Logistics And Green Issues

Reverse logistics and green issues are emerging dimensions of supply chain management (Marien, 1998). This area examines both environmental issues and the reverse logistics issues of product returns. Because of legislation and consumer pressure, the growing importance of these issues is evident to most managers.

Reverse logistic is related to the process of recycling, reusing and reducing the material, i.e. goods or materials that are sent "backwards" in the supply chain. The issues faced in reverse logistics are not just the "reverse" issues of a traditional supply chain, they can be more complex, as for example, aspects related to the transportation and disposal of dangerous materials. By green issues, we usually understand the activities related with choosing the best possible means of transportation, load carriers and routes and reducing the environmental impact of the complete supply chain. Some of the areas clearly affected are packaging of products, transportation means and product development, as many others. Logistics is also involved in removal and disposal of waste material left over from the production, distribution or packaging process, as the recycling and reusable products. All the above make clear the relevance of the area of reverse logistics and green issues, since many companies have to re-organize their supply chains and even extend them to able the return, reuse or disposal of their product and materials. These pose many new and challenging questions to the area of SCM (Lourenço, 2002).

2.4.10. Outsourcing And Strategic Alliances

Outsourcing and strategic alliances examines the supply chain impact of outsourcing logistics services. Levels of logistics outsourcing are shown in Figure 2.2. There are five levels of logistics outsourcing (Bade et al., 1999):

1. In-house logistics, or insourcing logistics, or reverse outsourcing means that the company operates its logistics activities in-house. The company owns transport, warehouses, handling equipment, and others including staff to process the logistics functions. This traditional way can perform effectively and efficiently if the company pays attention (Langley et al, 2001; Wong et al, 2000).

2. Logistics service provider (LSP), or asset-based logistics (2PL) is the management of traditional logistics functions such as transport and warehouse. The company who does not own or have enough facilities and infrastructure may hire the LSP to provide the vehicles or the basic service. The major reason is to reduce the cost or capital investment.

3. Third party logistics (3PL/TPL), or forwarding logistics, or contract logistics. TPL in the original term means that using external organisations to perform logistics functions that can be the entire logistics process or selected activities (Skjoett-Larsen, 2000). Another explanation of 3PL by van Laarhoven et al. (2000) is activities carried out by a logistics service provider on behalf of a shipper and consisting of at least management and execution of transportation and warehousing for at least one year of cooperation on or off contract. Murphy & Poist (2000) defined 3PL as "A relationship between two parties or more which, compared with basic logistics services, has more customized offerings, encompasses a broader number of service functions and is characterized by a longer-term, more mutually beneficial relationship".

Skjoett-Larsen (2000) and Moore (1998) described 3PL as the same meaning as logistics alliance or strategic alliance that is a close relationship between a company and a logistics provider not only to operate the logistics tasks but to emphasize on sharing information, risks and benefits under long -period contract.

4. Fourth party logistics (4PL/FPL), or supply chain logistics, or lead logistics provider (LLP). FPL is an evolutional concept of 3PL for better service response, customisation, and flexibility. FPL manages and runs complex logistics operations including resources, supply chain infomediary, control room, and architecture/integrator function.

5. Fifth party logistics (5PL) is developed to serve the e-business market. Those 3PL and 4PL providers manage all the parties in the supply chain on e-commerce. The key to success in this area is the information technology and system (Ge et al., 2004).

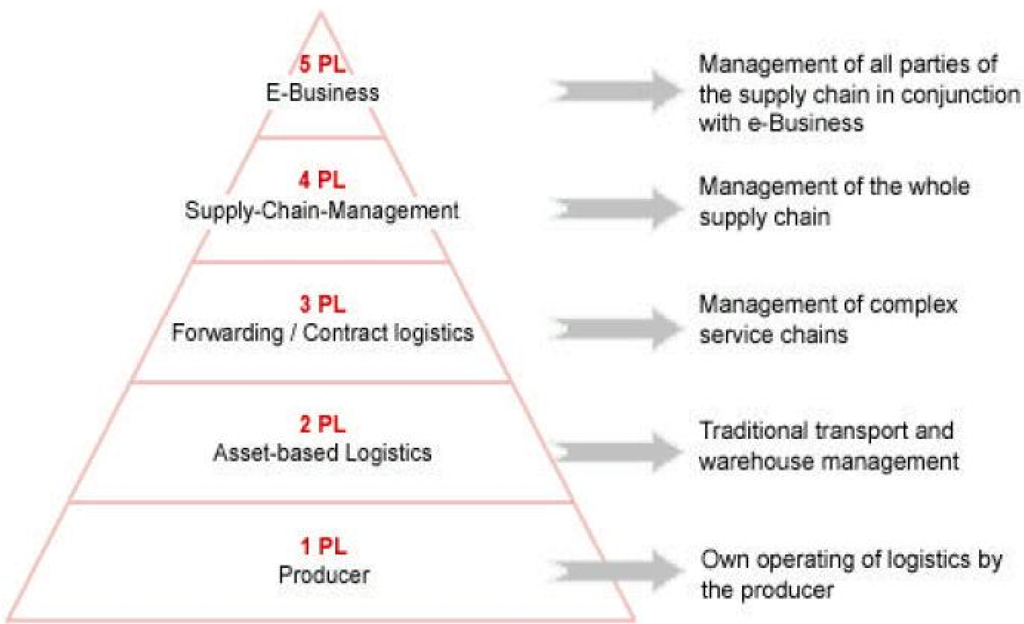


Figure 2.2 Levels of Logistics Outsourcing (Ding L. et al., 2004)

2.4.11. Metrics And Incentives

Metrics and incentives examine measurement and other organizational and economic issues. This category includes both measurement within the supply chain and industry benchmarking (Meyer, 1997).

Three purposes of metrics can be identified as (Melnyk et al., 2004): control, communication and improvement. According to Melnyk et al. (2004) literature has until now mainly focused on the use of metrics, but less on generating metrics and putting them into execution. They mention several reasons for an increased interest in performance measurement:

1. ever changing and ever increasing demands of customers,
2. the moving focus from internal operations to a chain of collaborating companies,
3. decreasing product life cycles,
4. increased amount of data (not necessarily data quality),
5. growing number of options a company can choose from.

Metrics need to move from static measurement to a more proactive style. Metrics will contribute to creating competitive advantages if they also allow on the spot recognizing of business oppurtunities as well as business threats.

2.4.12. Global Issues

Global issues examine how all of the above categories are affected when companies operate in multiple countries. This category goes beyond country specific issues, to encompass issues related to cross-boarder distribution and sourcing (Kouvelis, 1999). For example, currency exchange rates, duties and taxes, freight forwarding, customs issues, government regulation, and country comparisons are all included.

When a global supply chain is considered, most of the local issues play a role in the analysis. But there are other issues that may need to be taken into account. Some of these are technical. Others have nothing to do with the technology.

When designing for a global logistics network, issues like duty need to be taken into account. Most decision-support systems are capable of taking into account exchange rates, duties, and so forth. The technical part is not that big a problem. The bigger issue is risk. First, changes in exchange rates change the relative value of production and the value of selling a product in a particular country. Similarly, government reactions to a company's entering a new region play an important role in the global supply chain. Finally, political instabilities may affect global companies. The impact of these forces on the global corporation may be huge.

Of course, there are a number of strategies that a global supply chain can employ to address global risks. For instance, the company may use a hedging strategy where the supply chain is designed so that losses in one part of the supply chain will be offset by gains in other parts of the supply chain (Quinn, 2000).

Supply chain management is an exploding field, both in research and in practice. These twelve areas appear to be somewhat disparate, but they are all linked by the integrated nature of the problems at hand. Firms deal with multiple suppliers and customers, are required to manage inventories in new and innovative ways, and are faced with possible channel restructuring. The field promises to continue growing as the research advances and as firms continue to apply new knowledge in their global networks. Finally, as the Internet changes fundamental assumptions about business, firms operating in supply chains will be required to understand this new phenomenon and respond accordingly.

2.5. Supply Chain Management Decisions

The Supply Chain Management decisions are classified into 3 hierarchical levels based on the time horizon: Strategic (long-term), tactical (medium-term), and operational (short-term and real-time) decisions (Teigen, 1997).

Figure 2.3 shows the three level of decisions as a pyramid shaped hierarchy. The decisions on a higher level in the pyramid set the conditions under which lower level decisions are made.

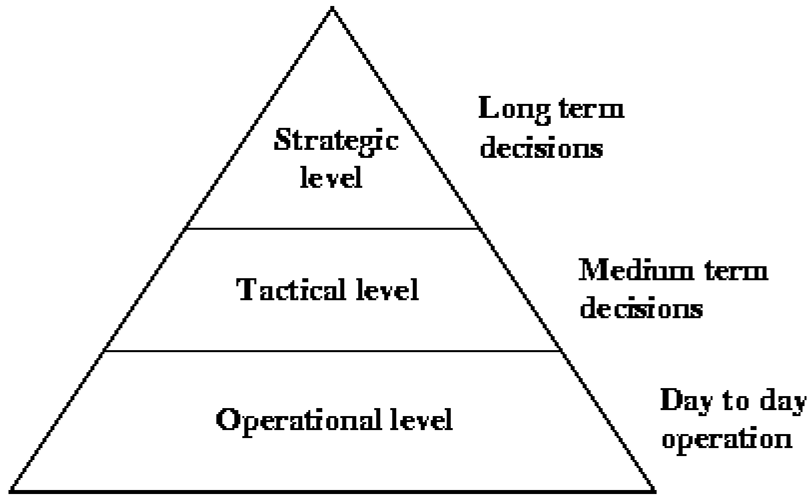


Figure 2.3 Hierarchy of Supply Chain Decisions (Teigen, 1997)

2.5.1. Strategic Decisions

Strategic decisions are made typically over a longer time horizon. These decisions are also called configuration decisions. They tend to have longer implementation cycles and often require the participation of partner companies in the supply chain. Examples are supplier selection decisions, change of business practices, creation of redundant capacity, product redesign (Robust Lean Supply Networks, 2003).

Decisions made on the strategic level are the most far-reaching and difficult to make. These decisions are characterized by complexity and uncertainty (Hicks, 1999). They are also interrelated. For example decisions on mode of transport are influenced by decisions on geographical placement of plants and warehouses, and inventory policies are influenced by choice of suppliers and production locations. Modeling and simulation is frequently used for analyzing these interrelations, and the impact of making strategic level changes in the supply chain.

Strategic decisions are anticipatory, i.e. they best prepare the supply chain to meet risk and uncertainty. Typically, the effects of strategic decisions become evident 1-5 years into the future (Robust Lean Supply Networks, 2003).

Strategic decisions are related to location, production, inventory, and transportation. Location decisions are concerned with the size, number, and geographic location of the supply chain entities, such as plants, inventories, or distribution centers. The production decisions are meant to determine which products to produce, where to produce them, which suppliers to use, from which plants to supply distribution centers, and so on. Inventory decisions are concerned with the way of managing inventories throughout the supply chain. Transport decisions are made on the modes of transport to use (Ganeshan & Harrison, 1995).

The implementation of strategic decisions enables better and more informed tactical and operational decisions. For example, putting in place the supplier selection system ensures that only those that meet the selection criteria are used, improving better day-to-day operation (Robust Lean Supply Networks, 2003).

The strategic decisions are global or "all encompassing" various aspects of the supply chain. Consequently, the models that describe these decisions are huge, and require a considerable amount of data. Often due to the enormity of data requirements, and the broad scope of decisions, these models provide approximate solutions to the decisions they describe (Ganeshan & Harrison, 1995).

"Network design" methods are used as supply chain modeling approaches for the strategic decisions. These methods typically cover the location, production, inventory, and transportation decisions and focus more on the design aspect of the supply chain; the establishment of the network and the associated flows on them. "Network design" methods are included in detail in section 5.4.1.

And also "simulation" methods is a method by which a comprehensive supply chain model can be analyzed, considering both strategic and operational elements. However, as with all simulation models, one can only evaluate the effectiveness of a prespecified policy rather than develop new ones. It is the traditional question of "What If?" versus "What's Best?" (Ganeshan & Harrison, 1995). "Simulation" methods are included in detail in section 5.4.3.

2.5.2. Tactical Decisions

Tactical decisions are made over a mid-range time horizon (1-12 months). Here longer term planning and scheduling decisions have to be taken, e.g., the master production schedule for the whole supply chain which also creates the master schedules for transportation and storing, and inventory decisions or make or buy decisions for all kinds of tasks (Sauer & Appelrath, 2002). These operations must handle both information processing and material controls, and often face to the difficulty to make decisions in various management phases. The optimal implementation often faces to re-engineering issues of business processes and decision processes.

The tactical operations in supply chain management covers various practical problems. The significant examples of such problems includes, material/location selection problems, capacity planning, lot-size planning, transportation channel planning, resource location planning, and others (Umeda & Jones, 1998).

The border between the tactical and operational levels is vague. Often no distinction is made.

"Rough cut" methods are used as supply chain modeling approaches for the operational and tactical decisions. These methods typically assume a single site and add supply chain characteristics to it, such as explicitly considering the site's relation to the others in the network (Ganeshan & Harrison, 1995). "Rough cut" methods are included in detail in section 5.4.2.

2.5.3. Operational Decisions

The operational decisions are made over a short term horizon (typically up to a month), and focus on activities over a day-to-day basis. They involve day-to-day ERP-driven activities like production planning, emergency measures, production scheduling in different production sites, storage scheduling within warehouses etc (Sauer & Appelrath, 2002). The nature of these decisions is fundamentally reactive – supply chain managers observe their supplier environments and track day-to-day changes in supply performance along a number of dimensions, like quality, timeliness, response to new requests, etc. Their actions are based on their interpretation of these signals (Robust Lean Supply Networks, 2003). The border between the tactical and operational levels is generally vague.

The models that describe the operational decisions are often very specific in nature. Due to their narrow perspective, these models often consider great detail and provide very good, if not optimal, solutions to the operational decisions.

"Rough cut" methods and "simulation" methods are used as supply chain modeling approaches for the operational decisions as mentioned before (Ganeshan & Harrison, 1995).

While there are many strategic, tactical, and operational decisions that must be considered in designing and operating supply chain networks (SCN), this thesis primarily focuses on strategic decisions that include the selection of supplier partners, distribution centers and finally transshipment between manufacturers and selected suppliers.

2.6. Supply Chain Modeling Approaches

Supply chain modeling approaches are divided into three areas: Network design, rough cut methods and simulation based methods (Ganeshan & Harrison, 1995).

2.6.1. Network Design Methods

Network design methods determine the location of production, stocking, and sourcing facilities, and paths the products take through them. Such methods tend to be large scale, and used generally at the inception of the supply chain.

Zangwill (1969) proposed a deterministic multi-product, multi-facility production, and inventory model. The model considers concave production costs, which can depend on the production in several different facilities, and piecewise concave inventory costs. Furthermore, backlogging of unsatisfied demand is permitted. This study is focused on determining an optimal production schedule, which specifies how much each facility in the network should produce so that the total cost is minimized.

Geoffrion & Graves (1974) introduced a multi-commodity logistics network design model for optimizing annualized finished product flows from plants to the DC's to the final customers. Geoffrion & Powers (1993) presented a review of the 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.

Breitman & Lucas (1987) attempted to provide a framework for a comprehensive model of a production-distribution system, "PLANETS", that is used to decide what products to produce, where and how to produce it, which markets to pursue and what resources to use.

Cohen & Lee (1985) developed a conceptual framework for manufacturing strategy analysis, where they describe a series of stochastic sub-models, that considers annualized product flows from raw material vendors via intermediate plants and distribution echelons to the final customers.

Cohen & Lee (1988) developed a model structure that can be used to predict the performance of a firm with respect to 1) cost of its product, 2) the service level, and 3) the responsiveness and flexibility of the production/distribution system. They represented an integrated, hierarchical, and stochastic network model structure consisting of four sub models, where each represents a part of the overall supply chain network. The four sub models are:1) material control sub model, 2) production control submodel, 3) finished goods stockpile sub model, and 4) distribution network control sub model. They used heuristic methods to connect and optimize all four sub models.

Cohen & Lee (1989) presented a normative model for resource deployment in a global manufacturing and distribution network. Global after-tax profit (profit-local taxes) is maximized through the design of facility network and control of material flows within the network. The cost structure consists of variable and fixed costs for material procurement, production, distribution and transportation. They validate the model by applying it to analyze the global manufacturing strategies of a personal computer manufacturer.

Farkas et al. (1993) presented a case study about linear programming optimization of a network for an aluminum plant. The mathematical structure of their problem is a generalized network with constraints such as capacity constraints and flow constraints between each node. They used linear programming to optimize the objective function that includes 134 decision variables and 142 constraints. This study considers only a deterministic case.

Finally, Arntzen et al. (1995) provided the most comprehensive deterministic model for supply chain management. The objective function minimizes a combination of cost and time elements. Examples of cost elements include purchasing, manufacturing, pipeline inventory, transportation costs between various sites, duties, and taxes. Time elements include manufacturing lead times and transit times. Unique to this model was the explicit consideration of duty and their recovery as the product flowed through different countries.

These network design based methods add value to the firm in that they lay down the manufacturing and distribution strategies far into the future. It is imperative that firms at one time or another make such integrated decisions, encompassing production, location, inventory, and transportation, and such models are therefore indispensable.

Although the above review shows considerable potential for these models as strategic determinants in the future, they are not without their shortcomings. Their nature forces these problems to be of a very large scale. They are often difficult to solve to optimality. Furthermore, most of the models in this category are largely deterministic and static in nature. Additionally, those that consider stochastic elements are very restrictive in nature. In sum, there does not seem to yet be a comprehensive model that is representative of the true nature of material flows in the supply chain (Ganeshan & Harrison, 1995).

2.6.2. Rough Cut Methods

These models typically deal with the more operational or tactical decisions. Most of the integrative research (from a supply chain context) in the literature seem to take on an inventory management perspective. In fact, the term "Supply Chain" first appears in the literature as an inventory management approach. The thrust of the rough cut models is the development of inventory control policies, considering several levels or echelons together. These models have come to be known as "multi-level" or "multi-echelon" inventory control models (Ganeshan & Harrison, 1995).

Multi-echelon inventory theory has been very successfully used in industry. Cohen et. al. (1990) described "OPTIMIZER", one of the most complex models to date, to manage IBM's spare parts inventory. They develop efficient algorithms and sophisticated data structures to achieve large scale systems integration.

Although current research in multi-echelon based supply chain inventory problems shows considerable promise in reducing inventories with increased customer service, the studies have several notable limitations. First, these studies largely ignore the production side of the supply chain. Their starting point in most cases is a finished goods stockpile, and policies are given to manage these effectively. Since production is a natural part of the supply chain, there seems to be a need with models that include the production component in them. Second, even on the distribution side, almost all published research assumes an arborescence structure, i. e. each site receives re-supply from only one higher level site but can distribute to several lower levels. Third, researchers have largely focused on the inventory system only. In logistics-system theory, transportation and inventory are primary components of the order fulfillment process in terms of cost and service levels. Therefore, companies must consider important interrelationships among transportation, inventory and customer service in determining their policies. Fourth, most of the models under the "inventory theoretic" paradigm are very restrictive in nature, i.e., mostly they restrict themselves to certain well known forms of demand or lead time or both, often quite contrary to what is observed (Ganeshan & Harrison, 1995).

2.6.3. Simulation

A good explanation to the simulation is given by Law & Kelton (1991): ”If the relationships that compose the model are simple enough, it may be possible to use mathematical methods (such as algebra, calculus, or probability theory) to obtain exact information on questions of interest; this is called an analytic solution. However, most real-world systems are too complex to allow realistic models to be evaluated analytically, and these models must be studied by means of simulation. In a simulation, we use a computer to evaluate a model numerically, and data are gathered in order to estimate the desired true characteristic of the model.”

Simulation is often used to test the impact strategic level decisions have on supply chain performance. This may for example be the impact of restructuring the supply chain by reducing the number of plants, changing modes of transport, or relocating warehouses. Simulation as a method, does not give the optimal solution. It simply allows the user to test different solutions. Simulations are run with various parameters or ”set-ups”, and the results are analyzed and compared to arrive at the optimal solution among those tested (Teigen, 1997).

Berry & Naim (1999) developed simulation models that describe the dynamic implications of various supply chain redesign strategies adopted by a major European manufacturer of personal computers. They stated that the simulation modeling is useful in educating and informing supply chain designers in other supply chains of the relative dynamic benefits of different supply chain redesign strategies.

Simulation technology is emerging as a new tool in supply chain management and its basic strength is in evaluating system variation and interdependencies. This key component allows a decision maker to evaluate changes in part of the supply chain and visualize the impact those changes have on the other system components and ultimately the performance of the entire supply chain (Wyland et. al., 2000).

In this thesis a two-phase mathematical programming approach is used to design a SCN, which involves a variety of techniques that include multi-criteria efficiency models, based on game formulations, and linear and integer-programming methods.

2.7. Supply Chain Network Structure

The supply chain network (SCN) structure is the member firms and the links between these firms. All firms participate in a supply chain from the raw materials to the ultimate consumer. How much of this supply chain needs to be managed depend on several factors, such as the complexity of the product, the number of available suppliers, and the availability of raw materials (Brewer et al., 2001). Firms need consider the length of the supply chain and the number of the suppliers and customers at each level. Therefore, it is important to have an explicit knowledge and understanding of how the supply chain network structure is configured. The typical approach is to use a network model. A network model graphically visualizes a supply chain and is used to depict the parts of a supply chain being considered in the business process.

The members of a supply chain include all companies/organizations with whom the focal company interacts directly or indirectly through its suppliers or customers, from point of origin to point of consumption. Figure 2.4 represents a supply chain network formed by focal company and the members of focal company's supply chain.

SCNs are considered as a solution for effectively meeting customer requirements such as low costs, high product variety, high quality, and short lead times. However, the success of SCNs depends to a large extent on how effectively they are designed and operated. While network design involves the selection of competent and compatible business processes that design, produce, and distribute the product, network operation includes exact sourcing and deployment plans (Talluri & Baker, 2002).

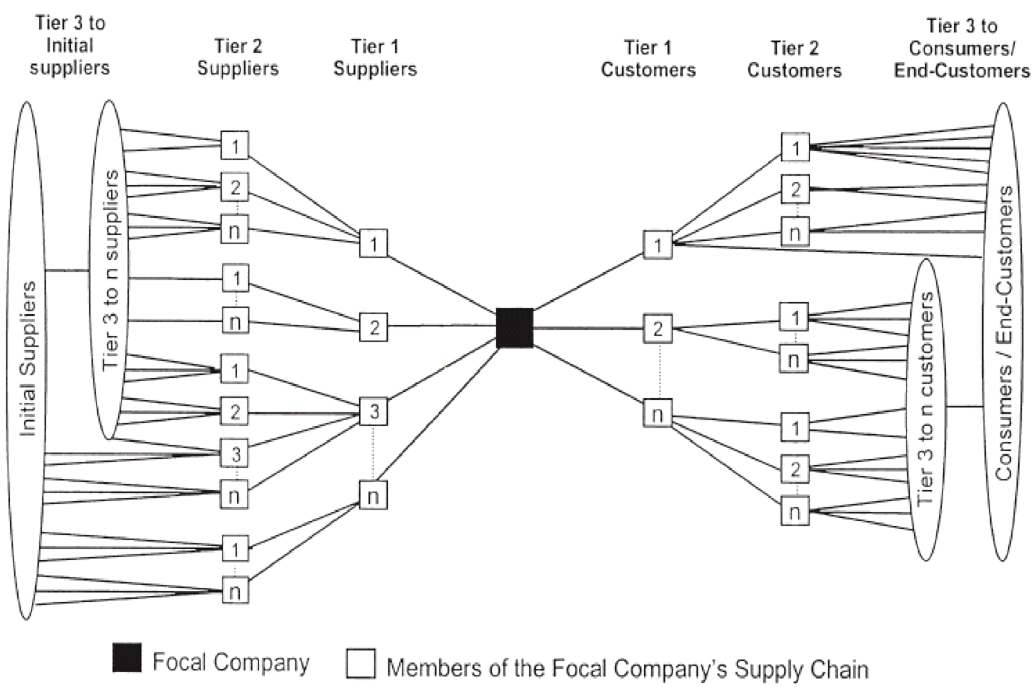


Figure 2.4 Supply chain network structure (Lambert et. al., 1998)

In general, three structural dimensions of the network are essential when describing, analyzing, and managing the supply chain. These dimensions are the horizontal structure, the vertical structure, and the horizontal position of the focal company within the end points of the supply chain. The horizontal structure refers to the number of tiers across the supply chain. The supply chain may be long, with numerous tiers, or short, with few tiers. The vertical structure refers to the number of suppliers / customers represented within each tier. A company can have a narrow vertical structure, with few companies at each tier level, or a wide vertical structure, with many suppliers and/or customers at each tier level. The third structural dimension is the company's horizontal position within the supply chain. A company can be positioned at or near the initial source of supply, be at or near to the ultimate customer, or somewhere between these end points of supply chain. According to the research, different combinations of these structural variables were found in the companies (Lambert & Cooper, 2000).

In order to manage its demand and product flows, common operations of demand forecasting, inventory planning and control, capacity planning, purchasing, warehousing and distribution are conducted in this supply chain network. An implementation of this special relationship among business entities is a supply chain management system. The closeness of the relationship at different points in the supply chain will differ. Management will need to choose the level of partnership appropriate for particular supply chain links.

As a network, it involves bi-directional flows of materials, information and payments. Supply chains exist in virtually every industry, especially industries that involve product manufacturing, and management of supply chains is not an easy task because of the large amount of activities that must be coordinated across organizational and global boundaries. Not all links throughout the supply chain should be closely coordinated and integrated. The most appropriate relationship is the one that best fits the specific set of circumstances. Determining which parts of the supply chain deserve management attention must be weighed against firm capabilities and the importance to the firm (Brewer et al., 2001). A proper structural foundation of the supply chain allows flexible representation and implementation of prescriptive models to improve its performance through cooperation among its members.

2.8. Supplier Evaluation And Selection

2.8.1. Definitions

Supplier evaluation is defined as the process of quantifying action, or more specifically the process of quantifying and analyzing effectiveness and efficiency. Effectiveness is defined as the extent to which goals are accomplished and efficiency is a measure of how well the firm's resources are utilized to achieve specific goals. Selection and evaluation of supplier is the foundation of supply chain's operating.

During the recent years, supply chain management and the supplier selection process have received considerable attention in the literature. Miller et al. (1981) classified supply strategies as one of the strategic operating choices.

The question of 'who to buy from and how much to buy' is the supplier selection problem. According to De Boer et al., (2001) a supplier selection problem typically consists of four phases,(1) finding out exactly what we want to achieve by selecting a supplier (2) defining the criteria (3) qualification of suitable suppliers to (4) making a final choice. Basically there are two kinds of supplier selection problem:

1. Supplier selection when there is no constraint. In other words, all suppliers can satisfy the buyer's requirements of demand, quality, delivery.

2. Supplier selection when there are some limitations in suppliers' capacity, quality, etc. In other words, no one supplier can satisfy the buyer's total requirements and the buyer needs to purchase some part of his/her demand from one supplier and the other part from another supplier to compensate for the shortage of capacity or low quality of the first supplier.

The first supplier selection problem involves making only one decision, which supplier is the best since one supplier can satisfy all the buyer's needs (Single Sourcing). Whereas the second problem involves selecting more than one supplier since no supplier can satisfy all the buyer's requirements (Multiple Sourcing). Under these circumstances, management needs to make two decisions: which suppliers are the best, and how much should be purchased from each selected supplier (Ghodsypour & Brien, 1998).

Each strategy has its own advantages and disadvantages. These are discussed below:

Advantages of Single Sourcing:

- The order may be so small that it is not worthwhile to be divided. Splitting the order may increase fixed purchasing costs.
- Concentrating purchases may make possible certain discounts or lower freight rates that could not be had otherwise.
- The supplier will be more cooperative, more interested and more willing to please if it has all the buyer's business.
- Deliveries may be more easily scheduled.
- Effective supplier relations require considerable resources and time. Therefore the fewer supplier the better.

Advantages of Multiple Sourcing:

- Knowing that competitors are getting some of the business may tend to keep the supplier more alert to the need for giving good prices and service.
- Assurance of supply is increased. In case of fires, accidents, breakdowns, deliveries can still be obtained.
- Supplier dependence is avoided.

- More flexibility is achieved since the unused capacity of all suppliers is available.
- Strategic reasons such as military preparedness and supply security may require multiple sourcing.
- Capacity of a single supplier may not be enough to carry out the current or future needs of the firm (Leenders & Fearon, 2000).

2.8.2. Literature Survey

Supplier selection is a multi-criteria problem and there are not a lot of efficient techniques or algorithms that addresses this problem. The conventional methods that are being used for supplier evaluation like total-cost of ownership models, linear weighted models etc., are very subjective in nature. They are subjective because the buyer assigns values to various factors that are involved in selection of suppliers and the values vary from one buyer to another for the same supplier. So the need for methods/algorithms that are more objective in nature, that involves assigning common set of values to the selection criteria, is to be used.

This section includes a survey of current literature focusing on the problem of supplier selection.

Soukup (1987) developed a supplier performance matrix to evaluate suppliers from the view of prices offered. In this matrix the expected requirements and their probabilities as well as the suppliers and their offers are listed. The expected cost for each supplier is calculated by multiplying the volume, the offered price (for that volume) and the probability (of that volume). The lowest expected cost and the corresponding supplier is chosen for that order.

Mazurak et al. (1985) used a spreadsheet software for purchasing as well as supplier selection decisions. Different suppliers are evaluated with respect to their product quality, price, service and their financial condition in the past.

A similar study is carried out by Gregory in 1986. He proposed the use of a matrix approach in supplier selection. A sourcing worksheet is used to evaluate suppliers. All criteria, the weights of the criteria and the performance measures of each supplier are listed in this sheet. The measures of the suppliers are determined rather subjectively. The weighted total scores are then computed. Unlike this study, Mazurak et al. (1985) chose only the supplier that has the highest score, the orders are split between the two best suppliers. The share of each supplier is calculated proportional to its scores on the worksheet. This study applies multiple sourcing rather than single sourcing. There also exist other methods to allocate the order quantities between different suppliers.

And also there are other methods to allocate the order quantities between different suppliers. Chaudhry, Forst & Zydiak (1991) used an integer goal-programming model to solve a supplier selection problem under consideration of four goals, which are quality, lead-time, service and price goals. The model is solved using the Lindo software.

In supplier selection problems, a lot of qualitative factors as well as quantitative ones are considered. Korhonen & Wallenius (1990) used analytical hierarchy process (AHP) to quantify the qualitative data on hand. Then they applied multiple-objective linear programming approach to solve the supplier selection problem. This approach was implemented using a multiple criteria decision support system VIG, (Visual Interactive Goal Programming) developed by Korhonen. VIG is used in many studies. One of these is multi-objective decision making in supplier selection by Karpak et al. (1999). They used a VIG model to identify appropriate suppliers and allocate purchase orders among them while minimizing product acquisition costs and maximizing total product quality and delivery reliability. In their two different examples, the models end up with both which suppliers to select and the quantities to be ordered to them. VIG sees the constraints of the problem as goals. Constraints are called inflexible goals whereas the objectives are called flexible goals. The approach starts with finding the best possible value for the flexible goals. This solution may not be feasible yet. For this reason, the inflexible goals, which are violated by the initial solution are relaxed and turned into flexible goals one by one. By this way the solution becomes feasible.

Houshyar & Lyth (1992) presented a systematic procedure in making supplier selection decisions. They classify the factors as critical, objective and subjective. The critical factors are the ones, which take a supplier into the choice list or throw out totally. The first step in the procedure is to define all three types of factors. Then the suppliers, which pass the critical factors are listed. The second step is to evaluate the suppliers in the list in terms of objective and subjective factors using the matrix approach and AHP, respectively. The two different measures are brought together with the desired weights. The last step is to list the suppliers from the highest to the lowest according to their overall scores. Whether to employ single or multiple sourcing is left up to the decision-maker.

Akinc (1993) proposed a decision support approach for selecting suppliers under four objectives: minimizing the material costs, reducing the number of suppliers and maximizing suppliers’ delivery and quality performances. Heuristics is used to solve the problems.

Weber & Current (1993) proposed a multi-objective approach to supplier selection. The proposed model aims at minimizing the price, maximizing the quality and on time delivery. A linear combination of these objectives become the objective function. Mixed integer problem is developed and solved. Two sets of constraints are taken into account: (1) systems' constraints, which are defined as the constraints which are not directly under the control of the purchasing managers such as supplier capacities, demand satisfaction, minimum order quantities established by the suppliers and the total purchasing budget; and (2) policy constraints, including maximum and/or minimum order quantities purchased from a particular supplier, and the maximum and/or minimum number of suppliers to be employed.

In another study, Weber & Current (1994) formulated the supplier selection problems within the mathematical constructs of facility layout models and they presented the similarities between the supplier selection problem and facility layout models.

Ghodsypour & Brien (1998) also employed AHP. They integrated analytical hierarchy process and linear programming to deal with both qualitative and quantitative factors in choosing the best suppliers. In this work, first the criteria for supplier selection are defined and their weights are computed using AHP. All the suppliers are evaluated and their total scores are achieved. Later, a linear programming model is built and solved. The objective is to maximize the total value purchased which is found by multiplying the suppliers overall scores and the quantity to be ordered from that supplier. The constraints are the capacity, quality and the demand.

Kasilingan & Lee (1996) also studied the supplier selection problem. They built a mixed integer-programming model considering the demand as stochastic. The quality factor is considered as the cost of poor quality parts. This cost is included in the objective function as well as the purchasing, transportation costs and the fixed cost of establishing suppliers.

Ulusam & Kurt (2002) applied fuzzy goal programming in purchasing problem. They defined cost, quality, delivery reliability goals as fuzzy goals. These are transformed into a linear programming form.

As mentioned above, there is a strong challenge moving from single sourcing to multiple sourcing. The first studies used to solve supplier selection were choosing only one supplier and placing the orders from it. However, as new methods are developed, a supplier selection problem became not only choosing the suppliers but also allocating order quantities among them.

In this thesis, a two-phase mathematical programming method considering both tangible and intangible factors is developed to select the suppliers and distributors and to solve the transshipment problem. Supplier and distributor selection models and methods are discussed in detail in chapter 3.

2.8.3. Supplier Selection Criteria

Supplier selection is performed through a careful supplier selection process in which suppliers are evaluated according to different criteria. The supplier selection literature has long held that product quality, delivery, price and service are the key attributes that are used to assess the performance capabilities of suppliers. The importance of the respective decision criteria has changed over time and while earlier studies reported that delivery and price were most important, later research found that quality had become most prominent (Bharadwaj, 2003).

It must be noted that a great number of factors affect a supplier's performance. Stamm & Golhar (1993), Ellram (1990) and Roa & Kiser (1980) identified 13, 18, and 60 criteria for supplier selection, respectively. Hence supplier selection is a multi-criteria problem requiring to make a trade-off between conflicting tangible and intangible factors to find the best suppliers.

Another study which considered 23 criteria for supplier selection was carried out by Dickson (1996). As seen in Table 2.1, quality and delivery are given the highest ranking. And also performance history, warranties and production facilities and capacity are considered to be quite important. Price factor is the sixth in the list, which shows that quality and delivery are much more important than lower prices in today's world.

It can be argued that it is extremely difficult for any one supplier to excel in all dimensions of performance. For example, a high quality supplier might not be the one with lowest cost components. It is also possible that the components delivered by a particular supplier excel in a few quality dimensions (reliability, features) while some other supplier might be superior in other quality dimensions (for example, durability or aesthetics). Therefore, the choice of suppliers generally involves trade-off among the attribute levels of different suppliers (Ben-Akiva & Lerman, 1991).

Supplier and distributor selection models and methods are discussed in detail in chapter 3.

Table 2.1 Dickson's supplier selection Criteria (Weber et al.,1991)

Rank	Factor	Mean Rating
1	Quality	3,508
2	Delivery	3,417
3	Performance History	2,998
4	Warranties and Claim Policies	2,849
5	Production Facilities & Capacity	2,775
6	Price	2,758
7	Technical Capability	2,545
8	Financial Position	2,514
9	Procedural Compliance	2,488
10	Communication System	2,426
11	Position in Industry	2,412
12	Desire for Business	2,256
13	Management and Organization	2,216
14	Operating Costs	2,211
15	Repair Service	2,187
16	Attitude	2,12
17	Impression	2,054
18	Packaging Ability	2,009
19	Labor Relations Record	2,003
20	Geographical Location	1,872
21	Amount of Past Business	1,597
22	Training Aids	1,537
23	Reciprocal Arrangements	0,61

CHAPTER THREE

THE APPROACHES USED FOR SUPPLIER AND DISTRIBUTOR SELECTION

This section presents the approaches used in the literature for supplier and distributor selection. The supplier and distributor selection models and example methods are structured into the form of a hierarchy as shown in Figure 3.1.

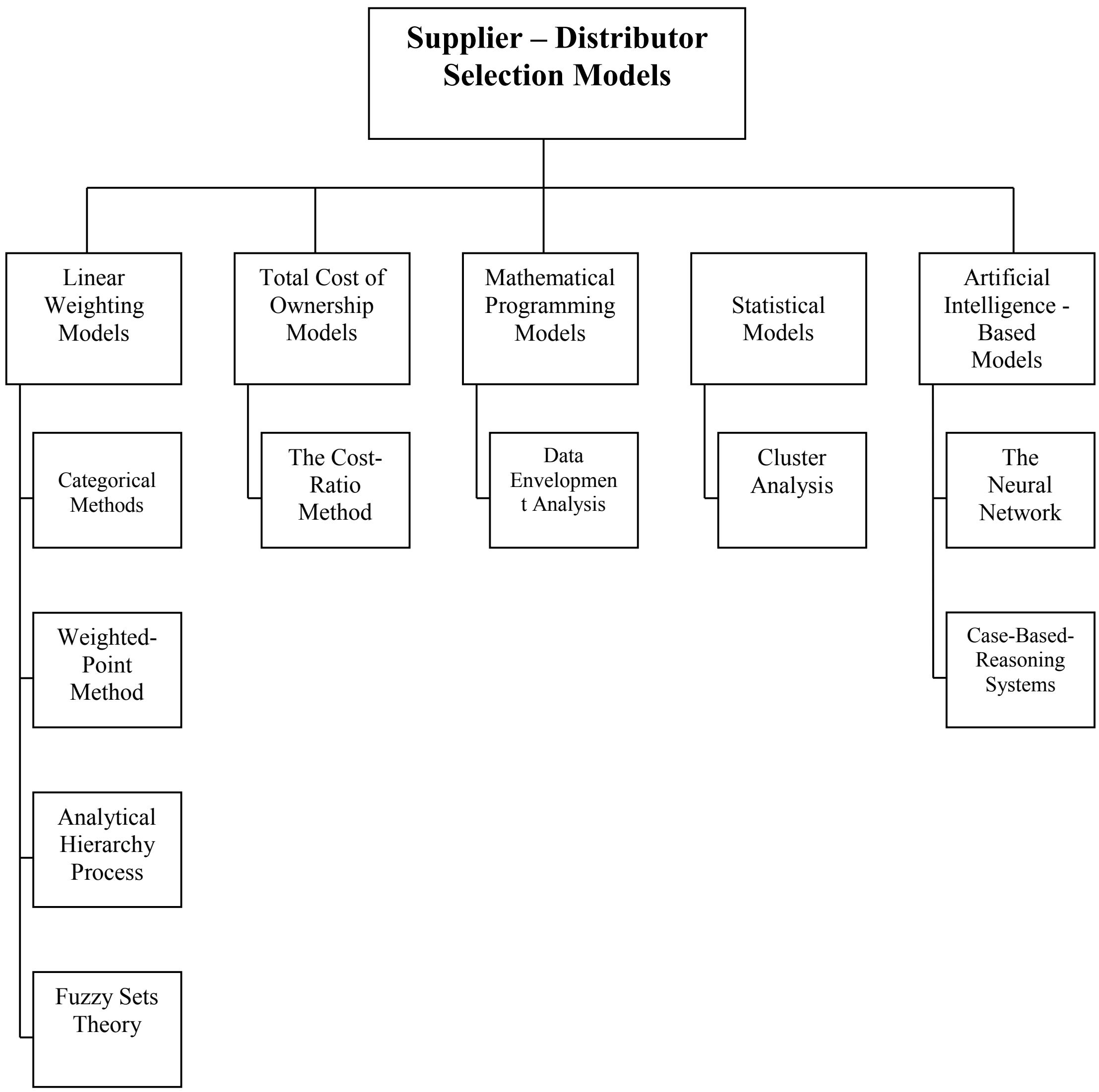


Figure 3.1 The supplier and distributor selection models and example methods

3.1. Linear Weighting Models

In linear weighting models, a weight is given to each criterion, the biggest weight indicating the highest importance. Ratings on the criteria are multiplied by their weights and summed in order to obtain a single figure for each supplier. The supplier with the highest overall rating can then be selected. Over the past 10 to 15 years a wide variety of slightly different linear weighting models have been suggested for supplier selection.

Examples of methods based on linear weighting models that have been applied to supplier selection include categorical methods, weighted point method, analytical hierarchy process and fuzzy sets theory.

3.1.1. Categorical Methods

The categorical method is a qualitative model. It is based on historical data and the buyer's experience with the current or familiar suppliers. Suppliers are evaluated on a set of criteria. The evaluations actually consist of categorising the supplier's performance on a criterion as positive, neutral or negative. After a supplier has been rated on all criteria, the buyer gives an overall rating. In this way, suppliers are sorted into three categories. This method relies heavily on the experience and ability of the individual buyer (Timmerman, 1986).

The primary advantage of the categorical approach is that it helps structure the evaluation process in a clear and systematic way. This method is quite simple, it is not supported by objective criteria, and rarely leads to performance improvements. It requires a minimum performance data and inexpensive. The main drawback of this method is that the identified attributes are weighted equally and the decisions made using this system tend to be fairly subjective and imprecise.

3.1.2. Weighted-Point Method

The weighted point method considers attributes that are weighted by the buyer. The weight for each attribute is then multiplied by the performance score that is assigned. Finally, these products are totaled to determine a final rating for each supplier (Timmerman, 1986). Typically this system is designed to utilize quantitative measurements.

The advantages of the weighted point method include the ability for the organization to include numerous evaluation factors and assign them weights according to the organization's needs. The subjective factors on the evaluation are minimized. The major limitation of this approach is that it is difficult to effectively take qualitative evaluation criteria into consideration.

3.1.3. Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is a decision-making method developed by Saaty (1980) for prioritizing alternatives when multiple criteria must be considered and allows the decision maker to structure complex problems in the form of a hierarchy, or a set of integrated levels. Generally, the hierarchy has at least three levels: the goal, the criteria, and the alternatives. For the supplier selection problem, the goal is to select the best overall supplier (Nydick & Hill, 1992).

The criteria can be quality, price, service, delivery, etc. The alternatives are the different proposals supplied by the suppliers. The AHP offers a methodology to rank alternative courses of action based on the decision-maker's judgments concerning the importance of the criteria and the extent to which they are met by each alternative. For this reason, AHP is ideally suited for the supplier selection problem.

The problem hierarchy lends itself to an analysis based on the impact of a given level on the next higher level. The process begins by determining the relative importance of the criteria in meeting the goals. Next, the focus shifts to measuring the extent to which the alternatives achieve each of the criteria. Finally, the results of the two analyses are synthesized to compute the relative importance of the alternative in meeting the goal.

Narasimhan (1983) was the first to use AHP to deal with imprecision in supplier selection. Later, Sarkis & Talluri (2000) and Sarkis & Sundarraj (2002) used analytical network process (ANP), a more sophisticated version of AHP, for supplier selection.

AHP is described in detail in section 4.2. In this thesis, AHP is used to select suppliers in designing a supply chain. For this purpose, first, all suppliers at each material type are selected by Data Envelopment Analysis, and then the priorities are obtained that will be used in transshipment problem as coefficients for these suppliers by AHP.

3.1.4. Fuzzy Sets Theory

Fuzzy sets theory (FST) is used to model uncertainty and imprecision in supplier selection situations. FST offers a mathematically precise way of modeling vague preferences. Simply stated, FST makes it possible to mathematically describe a statement like ”Criterion X should have a weight of around 0.8”. FST can be combined with other techniques to improve the quality of the final tools (Boer et. al., 2001).

Morlacchi (1997) developed a model that combines the use of fuzzy set with AHP and implements it to evaluate the suppliers in the engineering and machine sectors. In a subsequent work, Morlacchi (1999) focused on the design process of such supplier evaluation model, pointing to the advantages and the disadvantages of using hybrid approaches of techniques. In addition, Li et al. (1997) and Holt (1998) discuss edthe application of FST in supplier selection.

3.2. Total Cost of Ownership Models

Total cost of ownership (TCO) based models attempt to quantify all of the costs related to the purchase of a given quantity of products or services from a given supplier (Degraeve & Roodhooft, 1999).

Monczka & Trecha (1988) and Smytka & Clemens (1993) combined a total cost approach with rating systems for criteria such as service and delivery performance for which it is more difficult to obtain the cost figures. Degraeve & Roodhooft (1999) developed a mathematical programming model that uses total cost of ownership information to simultaneously select suppliers and determine order quantities over a multi-period time horizon.

Optimum use of all discounts available can lead to substantial savings. In addition to the price component, other cost factors also play an important role, including the costs associated with quality shortcomings, a supplier's unreliable delivery service, transport costs, ordering costs, reception costs, and inspection costs. This model uses activity-based costing which is a management accounting technique that attempts to assign costs to cost generating activities within a business.

The advantages of this model include substantial cost savings, the ability to identify the more important elements and allowing various purchasing policies to be compared with one another. The drawback of this model is that it is expensive to implement due its complexity and requires more time.

Example of a method based on TCO based models that have been applied to supplier selection is the cost-ratio method.

3.2.1. The Cost-Ratio Method

The cost-ratio method relates all identifiable purchasing costs to the monetary value of the goods received from suppliers (Timmerman, 1986). The higher the ratio of costs to value, the lower the rating applied to the supplier.

This method collects all costs related to quality, delivery and service and expresses them as a benefit or penalty percentage on unit price. The choices of costs to be incorporated in the evaluation depend on the products involved. The costs associated with quality include the costs of visits to a supplier's plants and sample approval, inspection costs of incoming shipments, and the costs associated with defective products such as unusual inspection procedures, rejected parts and manufacturing losses due to defective goods. Quality costs can be determined and documented by the quality control department, with the help of other departments such as production and receiving. The usual costs associated with delivery include communications, settlements and emergency transport costs. The same tabulation procedure is followed as for the quality costs. The cost-ratio method establishes a "norm" of supplier services and evaluates suppliers above and below the norm in relation to price. The subjective elements common to other methods are thus reduced.

Due the flexibility of this method, any company in any market can adopt it. The drawback of the method is its complexity and requirement for a developed cost accounting system

3.3. Mathematical Programming Models

Mathematical programming (MP) models allow the decision-maker to formulate the decision problem in terms of a mathematical objective function that subsequently needs to be maximised (e.g. maximise profit) or minimised (e.g. minimise costs) by varying the values of the variables in the objective function. On the one hand, it may be argued that MP-models are more objective than rating models because they force the decision-maker to explicitly state the objective function. On the other hand, MP-models often only consider the more quantitative criteria.

Some of the mathematical programming models focus on the modeling of specific discounting environments. Akinc (1993) concentrated on decision support regarding the number of suppliers. Benton (1991) presented a heuristic procedure to solve the multiple item problem with a non-linear objective function. Current & Weber (1994) used facility location modeling constructs for the supplier selection problem.

Das & Tyagi (1994) developed a decision support system for a wholesaler where the choice of the manufacturer is only one of several factors that has to be optimised in order to minimise the total cost of the wholesaling service.

Other issues include selecting warehouses, assigning transportation modes and determining the service level to retailers. Only Bender et al. (1985), Buffa & Jackson (1983) and Degraeve & Roodhooft (2000) simultaneously considered the inventory management and supplier selection decisions. However, in Bender et al. (1985) the mathematical programming model formulation is not included while Buffa & Jackson (1983) only solved a single-item problem.

Many of the mathematical programming models assume predetermined levels on quality, service and delivery constraints. Weber & Current (1993) overcomed this problem by using more complex weighting and constraint methods and presenting trade off curves among the multiple objectives as decision support to purchasing managers. Weber & Desai (1996) proposed data envelopment analysis (DEA) for evaluation of suppliers that were already selected. Weber, Current & Desai (1998) combined MP and the DEA method to provide buyers with a tool for negotiations with suppliers that were not selected right away as well as to evaluate different numbers of suppliers to use (Weber et al., 2000). For more information about DEA, see section 4.1.

Ghoudsypour & O'Brien (1998) combined AHP and MP in order to take into account tangible as well as intangible criteria and to optimise order allocation among suppliers. Karpak et al. (1999) used goal programming to minimise costs and maximise quality and delivery reliability when selecting suppliers and allocating orders between them.

Example of a method based on MP models that have been applied to supplier selection is data envelopment analysis.

3.3.1. Data Envelopment Analysis

Data envelopment analysis (DEA) was originally developed by Charnes, Cooper and Rodes, later, was extended by Banker, Charnes, and Cooper. DEA is built around the concept of the efficiency of a decision alternative. The alternatives are evaluated on benefit criteria (output) and cost criteria (input). The efficiency of an alternative (e.g. a supplier) is defined as the ratio of the weighted sum of its outputs (i.e. the performance of the supplier) to the weighted sum of its inputs (i.e. the costs of using the supplier). For each supplier, the DEA method finds the most favourable set of weights, i.e. the set of weights that maximises the supplier's efficiency rating without making its own or any other supplier's rating greater than one. In this way the DEA method aids the buyer in classifying the suppliers into two categories: the efficient suppliers and the inefficient suppliers.

DEA allows for the simultaneous analysis of multiple inputs to multiple outputs, a multi-factor productivity approach (Weber & Ellram, 1992). Weber & Ellram (1992), Weber & Desai (1996) and Weber et al. (1998) have primarily discussed the application of DEA in supplier selection. Weber shows not only categorising suppliers, but also how DEA can be used as a tool for negotiating with inefficient suppliers.

DEA focuses on calculating the overall operational efficiency of the suppliers and thus a supplier could be considered to have a relative efficiency of 1 if it produces a set of output factors that is not produced by other suppliers with a given set of input factors. Full (100%) efficiency is attained by a decision making unit (DMU) if none of its inputs or outputs can be improved without worsening some of its other inputs or outputs. DEA is used to compare DMUs, which use one or more inputs and one or more outputs to calculate relative efficiency. Inputs are the factors that are considered to influence in producing the chosen output factors.

It is difficult to evaluate an organization's performance when there are multiple inputs and multiple outputs to the system. The difficulties are further enhanced when the relationships between the inputs and the outputs are complex and involve unknown tradeoffs. Thus DEA is used to calculate the relative efficiency scores of multiple DMUs based on multiple inputs and outputs. This relative efficiency calculation can provide benchmarking data for reducing the number of suppliers, which in turn would result in effective supply chain management.

Over the past two decades, DEA has emerged as an important tool in the field of efficiency measurement, so in this thesis DEA is used to select suppliers and distributors to design a supply chain network. DEA is described in detail in section 4.1.

3.4. Statistical Models

Statistical models deal with the stochastic uncertainty related to the supplier selection. Although stochastic uncertainty is present in most types of purchasing situations, e.g. by not knowing exactly how the internal demand for the items or services purchased will develop, only very few supplier selection models really handle this problem. The published statistical models only accommodate for uncertainty with regard to one criterion at a time. Ronen & Trietsch (1988) developed a decision support system for supplier selection and ordering policy in the context of a large one/off project where the order lead-time is uncertain. Soukoup (1987) introduced a simulation solution for unstable demand in his rating model.

Example of a method based on statistical models that have been applied to supplier selection is the cluster analysis.

3.4.1. Cluster Analysis

Cluster analysis (CA) is a basic method from statistics which uses a classification algorithm to group a number of items which are described by a set of numerical attribute scores into a number of clusters such that the differences between items within a cluster are minimal and the differences between items from different clusters are maximal (Holt, 1998).

Obviously, CA can be applied to a group of suppliers that are described by scores on some criteria. The result is a classification of suppliers in clusters of comparable suppliers. Hinkle et al. (1969) were the first to report this, followed some 20 years later by Holt (1998).

3.5. Artificial Intelligence - Based Models

Artificial intelligence (AI)-based models are based on computer-aided systems that in one way or another can be trained by a purchasing expert or historic data. Subsequently, non-experts who face similar but new decision situations can consult the system. Although only few examples of AI methods applied to the supplier evaluation problem can be found in the literature to date it is important to investigate these methods for their potentials. Because of newness of some methods, such as Internet-based technology, only few examples with a demonstrative character are already available.

Examples of methods based on AI technology that have been applied to supplier selection include neural networks and case-based-reasoning systems.

3.5.1. The Neural Network

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurones) working in unison to solve specific problems.

The field of ANNs was pioneered by Bernard Widrow of Stanford University in the 1950s. ANNs are currently used prominently in voice recognition systems, image recognition systems, industrial robotics, medical imaging, data mining and aerospace applications. Since ANNs are best at identifying patterns or trends in data, they are well suited for prediction or forecasting needs including sales forecasting, industrial process control, customer research, data validation, risk management, target marketing.

ANN is also used to select suppliers. Using the ANN for supplier selection involves two functions: one is the function measuring and evaluating performance of purchasing (quality, quantity, timing, price and costs) and storing the evaluation in a database to provide data sources to neural network (Wei, 1997). The other is the function using neural network to select suppliers.

Comparing to conventional models, ANNs save time and money. One another strength of ANNs is that they do not require formalisation of the decision-making process. In that respect, ANNs can cope better with complexity and uncertainty than traditional methods, because AI-based approach is designed to be more like to human judgement functioning. The weakness of ANNs is that requires software and qualified personnel.

3.5.2. Case-Based-Reasoning Systems

Case-based-reasoning (CBR) systems are proposed by Cook (1997). CBR is a method for solving problems by making use of previous similar situations and reusing information and knowledge about such situations.

Basically, a CBR system is a software-driven database. CBR is still very new but some characteristics of CBR systems such as the capability to use information from previous negotiations and the easy training of the system, make it interesting in connection with supplier selection. For example Ng et al. (1995) developed a CBR system for the qualification of suppliers.

CHAPTER FOUR
DATA ENVELOPMENT ANALYSIS
AND
ANALYTICAL HIERARCHY PROCESS

4.1. Data Envelopment Analysis

4.1.1. Definition

Data envelopment analysis (DEA) as first introduced in 1978 (Charnes et al., 1978), is a linear programming-based technique that converts multiple input and output measures into a single comprehensive measure of productivity efficiency (Epstein & Henderson, 1989). DEA provides a measure by which one firm or department can compare its performance, in relative terms, to other homogeneous firms or departments.

Charnes et al. (1978) described DEA as a 'mathematical programming model applied to observational data that provides a new way of obtaining empirical estimates of relations - such as the production functions and/or efficient production possibility surfaces - that are cornerstones of modern economics'.

Epstein & Henderson (1989) described DEA as a useful management tool for both control and diagnosis. It assists in control as part of an output-based control strategy. In diagnosis it can serve as a tool that facilitates revelation of goals and preferences, assists in the identification and measurement of causal relationships, and for the detection and measurement of the impact of new technologies on production relationships.

DEA is mainly utilized under two different circumstances. First, it can be used when a department from one firm wants to compare its level of efficiency performance against that of a corresponding department in other firms. However, one major assumption is that all departments have similar strategic goals and directions

(Metters et al., 1999), which includes the need for all the firms to be within the same industry. Second, DEA can be used in a longitudinal nature by comparing the efficiency of a department or firm over time.

In measuring the relative efficiencies of organizations, the DEA measurement can be defined as the ratio of total weighted output to total weighted input. With DEA, each organization can utilize different weights for the set of performance measures. Weights are selected that will maximize the composite efficiency score for each functional unit. This allows each unit to take advantage of their own unique areas of specialization (Sexton, 1986). The efficiency score in the presence of multiple input and output factors is defined as:

$$\text{Efficiency} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}} \quad \text{(Talluri, 2000)}$$

When the input data of ratio have lower values and the output data of ratio have higher values, the relative efficiency has a higher performance. And also, when the input data are constrained to fixed values and the output data have higher values, the relative efficiency also has a higher performance (Liao, 2004).

DEA has a major advantage over benchmarking and other techniques where only one measure can be evaluated at a time. The single composite measure of DEA allows for the rank ordering of all the firms in terms of their overall performance (Easton et al., 2002).

A decision making unit (DMU), the name used by Charnes et al. (1978) to describe the units being analyzed in DEA, is to be rated as fully (100%) efficient on the basis of available evidence if and only if the performance of other DMUs does not show that some of its inputs or outputs can be improved without worsening some of its other inputs or outputs (Cooper et al., 2004).

The use of term DMU is intended to redirect the emphasis of the analysis from profit making businesses to decision-making entities. In other words, the analysis, which is performed can be applied to any unit based enterprise and needs have nothing to do with profit.

In this thesis, DEA is used as a tool to deal with the supplier and distributor selection problem in designing a supply chain.

4.1.2 Application Areas of DEA

DEA is an empirically based methodology that eliminates the need for some of the assumptions and limitations of traditional efficiency measurement approaches. It was originally intended for use as a performance measurement tool for organizations that lacked a profit motivation, e.g., not-for-profit and governmental organizations. However, since its introduction, it has been developed and expanded for a variety of uses in for-profit as well as not-for-profit situations.

Some applications have involved efficiency evaluation of organizations with characteristics similar to ports, such as hospitals (Banker et al., 1986) and (Sherman, 1986), schools (Ray, 1991) and (Charnes et al., 1981), courts (Lewin et al., 1982), post offices (Deprins et al., 1984), and air force maintenance units (Charnes et al., 1985). And also DEA has been used in situations such as the identification and measurement of the assessment of national parks efficiencies (Rhodes, 1986), the transportation sector (Banker & Johnston, 1994; Charnes et al., 1996), and railways (Oum & Yu, 1994). More recent examples include purchasing (Murphy & Pearson, 1996), flexible manufacturing systems (Sarkis, 1997), merchandising (Grewal & Levy, 1999) and production (Banker & Maindiratta, 1986).

Clarke & Gourdin (1991) applied DEA to the vehicle maintenance activities of 17 separate maintenance shops of a large-scale, nonprofit logistics system. They identified inefficient vehicle maintenance facilities, tested the perceived usefulness of DEA and demonstrated how DEA can be used in longitudinal studies to determine the progress of one unit or department over time.

Metzger (1993) used DEA to conduct a study to measure the effects of appraisal and prevention costs on productivity. They utilized step-wise regression to insure that only significant input variables were used in DEA. This study demonstrates the use of DEA as a measure of quality initiatives on productivity.

Application of DEA as a tool for strategic sourcing of suppliers has been limited. To date there have been few works that have applied this tool for supplier evaluation purposes.

Kleinsorge et al. (1992) utilized DEA as a tool for performance monitoring of a single supplier over time. However, their work did not address issues relating to strategic supplier selection or benchmarking. They presented the use of intangible measures with DEA.

Two articles by Weber & Desai (1996) and Weber et al. (1998) have addressed the issue of supplier selection and negotiation using DEA. The supplier metrics utilized in these studies were strictly operational ones. Weber & Desai (1996) identified inefficient suppliers for the purpose of negotiation leverage. They presented how parallel coordinates can be used to determine which aspects of supplier's performance need improvement in order to increase efficiency. Another study of Weber (1996) applied DEA in supplier evaluation for an individual product and demonstrated the advantages of applying DEA to such a system. In this study, six vendors supplying an item to a baby food manufacturer were evaluated and significant reductions in costs, late deliveries and rejected materials were achieved.

Narasimhan et al. (2001) have applied DEA for strategic evaluation of suppliers by considering various factors at both strategic and operational levels. While the approach in this study provided some useful insights into supplier evaluation and rationalization, the authors were also limited by the traditional DEA model evaluations. Also, this study has not investigated the reasons behind the differences in efficiency scores of suppliers, and thus did not delve into supplier improvement strategies.

4.1.3. Basic DEA Models

This subsection provides a brief review of two basic models developed in the DEA literature, namely, the Charnes, Cooper and Rhodes model (referred to as the CCR model) and the Banker, Charnes and Cooper model (referred to as the BCC model).

4.1.3.1. Charnes, Cooper, Rhodes (CCR) DEA Model

Charnes et al. (1978) initially introduced the CCR model to measure the relative efficiency of DMUs using multiple inputs to produce multiple outputs. For a given DMU, this model maximizes the output-to-input ratio. They addressed constant returns-to-scale (CRS). If an increase in a unit's inputs leads to a proportionate increase in its outputs i.e. there is a one-to-one, linear relationship between inputs and outputs, then the unit exhibits CRS. For example, if a 10% increase in inputs yields a 10% increase in outputs, the unit is operating at constant returns to scale. This means that no matter what scale the unit operates at, its efficiency will, assuming its current operating practices, remain unchanged.

The CRS efficiency represents technical efficiency, which measures inefficiencies due to input/output configuration and as well as size of operation (Sun, 2004).

The Charnes, Cooper, & Rhodes (CCR) (1978, 1979, 1981) ratio form of DEA named as model 1 is shown below (Bowlin, 1998):

$$\max h_o = \sum_{r=1}^{s} u_r y_{ro} \Big/ \sum_{i=1}^{m} v_i x_{io} \qquad (1)$$

s. t.

$$\left(\sum_{r=1}^{s} u_r\, y_{rj} \Big/ \sum_{i=1}^{m} v_i\, x_{ij} \right) \leq 1, \ \forall j, \quad (2)$$

$$u_r \Big/ \left(\sum_{i=1}^{m} v_i\, x_{io} \right) > \varepsilon , \ \forall r, \quad (3)$$

$$v_i \Big/ \left(\sum_{i=1}^{m} v_i\, x_{io} \right) > \varepsilon , \ \forall i, \quad (4)$$

$$\varepsilon > 0 , \quad (5)$$

$j = 1,....,n,$
$i = 1,....,m,$
$r = 1,....,s,$

where

y_{rj} = the amount of output r produced by DMU_j,

x_{ij} = the amount of input i utilized by DMU_j,

y_{ro} = the amount of output r produced by the target DMU (DMU_o),

x_{io} = the amount of input i utilized by the target DMU (DMU_o),

v_i = the weight given to input i,

u_r = the weight given to output r.

s = the number of outputs,

m = the number of inputs,

n = the number of DMUs.

DMU_o = the target DMU,

h_o = the efficiency score of DMU_o.

This model is designed to evaluate the relative performance of a DMU, designated as DMU_o, based on observed performance of j = 1,2,.....,n DMUs. A DMU is to be regarded as an entity responsible for converting inputs into outputs.

The y_{rj}, $x_{ij} > 0$ in the model are constants which represent observed amounts of the r^{th} output and the i^{th} input of the j^{th} decision making unit which is referred to as DMU_j in a collection of j =1,........,n entities which utilize these i = 1,......,m inputs and produce these r =1,......,s outputs.

The $\varepsilon > 0$ represents a non-archimedean constant, which is smaller than any positive valued real number. ε is introduced to ensure that all of the known inputs and outputs have positive weight values. In practice, this non-archimedean concept is handled by the DEA computer software used.

The numerator in (1) represents a set of desired outputs and the denominator represents a collection of resources used to obtain these outputs. This ratio results in a scalar value similar to ratio forms often used in accounting and other types of analyses. The value h_o^* obtained from this ratio satisfies $0 \leq h_o^* \leq 1$ and can be interpreted as an efficiency rating in which $h_o^* = 1$ represents full efficiency and $h_o^* \leq 1$ means inefficiency is present. h_o^* is the optimal value obtained from solving the model. Furthermore, h_o^* is invariant to the units of measure used for the input and output variables.

A DMU is CCR-efficient if and only if the optimal value to the problem (CCR) is equal to one. Otherwise, the DMU is said to be CCR-inefficient (Yun et al. 2004).

No weights need to be specified a priori in order to obtain the scalar measure of performance. The optimal values u_r^*, v_i^* may be interpreted as weights when solutions are available from model 1. But, they are determined in the solution of the model and not a priori. To emphasize differences from more customary (a priori) weighting approaches, the u_r^*, v_i^* values secured by solving the above problem are called virtual multipliers and interpreted in DEA so that they yield a virtual output, $Y_o = \sum u_r^* y_{ro}$ (summed over r = 1,...,s), and a virtual input, $X_o = \sum v_i^* x_{io}$ (summed over i = 1,...,m), which allows to compute the efficiency ratio $h_o = Y_o / X_o$.

As can be observed from model 1, this h_o^* is the highest rating that the data allow for a DMU. No other choice of u_r^* and v_i^* can yield a higher h_o^* and satisfy the constraints. These constraints make this a relative evaluation with:

$$\sum_{r=1}^{s} u_r y_{rj} / \sum_{i=1}^{m} v_i x_{ij} = 1 \qquad (6)$$

for some DMUs (denoted by j) as a condition of optimality.

Similar efficiency evaluations can be obtained for each of the j =1,.......,n DMUs listed in the constraints of model 1 by according them the same treatment, i.e., positioning them in the functional as DMU_o, one by one, while also leaving them in the constraints.

These efficiency ratings are more than just index numbers which indicate a ranking of DMUs based on their efficiency. The value of h_o^* has operational significance in that $1 - h_o^*$ provides an estimate of the inefficiency for each DMU_o being evaluated. This characterization makes it possible to identify the sources, the inefficiency in each input, and the output for every one of the DMUs being evaluated.

It is difficult to solve model 1 because of its fractional objective function. So it is converted into an ordinary linear programming problem where optimal value of the objective function indicates the relative efficiency for each DMU. The model named as model 2 can be expressed as follows:

$$\max \sum_{r=1}^{s} u_r y_{ro} \qquad (7)$$

s. t.

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \quad (8)$$

$$\sum_{i=1}^{m} v_i x_{io} = 1 \quad (9)$$

$$-u_r \leq -\varepsilon \quad (10)$$

$$-v_i \leq -\varepsilon \quad (11)$$

The first set of j =1,.....,n constraints in model 2 come from the less-than-or-equal-to unity requirements in model 1 while u_r, $v_i \geq \varepsilon > 0$, $\forall r$, i, come from the non-Archimedean conditions in model 1. Also, $\sum v_i x_{io} = 1$ guarantees that it is possible to move from model 2 to 1, as well as from model 1 to 2. Finally, the theory of fractional programming insures that:

$$h_o^* = \sum_{r=1}^{s} u_r^* y_{ro} \quad (12)$$

where the stars indicate optimal values in model 1 and 2, respectively.

The model 1 generalizes the usual single output to single input efficiency measures used in engineering and the natural sciences in a way that accommodates the case of multiple outputs and multiple inputs.

In the model 2, the objective is to maximize virtual output, subject to unit virtual input while maintaining the condition that virtual output cannot exceed virtual input for any DMU.

Since the model 2 is a linear programming problem, it has a dual, named as model 3, which can be represented as:

$$\min \theta - \varepsilon \left[\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right] \tag{13}$$

s. t.

$$\theta x_{io} - \sum_{j=1}^{n} \lambda_j x_{ij} - s_i^- = 0 \tag{14}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{ro} \tag{15}$$

$$\lambda_j , s_i^- , s_r^+ \geq 0 , \tag{16}$$

i=1,......m,
r=1,......s,
j=1,......n,

θ = relative efficiency score of DMU (θ is unrestricted in sign).
λ_j = dual variables
s_i^- , s_r^+ = slack variables

It is from model 3 that the name data envelopment analysis is derived. Any admissible choice of λ_j provides an upper limit for the outputs and a lower limit for the inputs of DMU_o and against these limits θ is tightened with λ_j^*, s_i^{-*}, $s_r^{+*} \geq 0$. The collection of such solutions then provides an upper bound which envelops all of the observations, and hence, leads to the name Data Envelopment Analysis.

Recalling that x_{io}, y_{ro} are represented in the constraints as well as in the model 1, it is clear that model 3 always has at least the solution θ =1, λ_o =1 and all other λ_j^*, s_i^{-*}, s_r^{+*} = 0 when DMU_o is the DMU under evaluation. It follows that an optimum will be attained with $0 \leq \theta^* \leq 1$. Because model 3 has a finite optimum, the duality theory of linear programming gives:

$$h_o^* = \theta^* - \varepsilon \left[\sum_{i=1}^{m} s_i^{-*} + \sum_{r=1}^{s} s_r^{+*} \right] = \sum_{r=1}^{s} u_r^* y_{ro} \quad (17)$$

θ^* =1 does not imply h_o^* = 1 unless s_i^{-*}, s_r^{+*} = 0 for all r and i. That is, all slack variables must also be zero in (17). Conversely, s_i^{-*}, s_r^{+*} = 0 for all r and i does not imply h_o^* =1 unless θ^* = 1. It is necessary to have both θ^*= 1 and zero slack for efficiency. In other words, h_o^* =1 implies θ^* =1 and all slack variables equal to zero in an optimum solution to (17) in order for DMU_o to be characterized as fully (100%) efficient via DEA. Therefore, h_o^* =1 if and only if DMU_o is efficient.

4.1.3.2. Banker, Charnes, and Cooper (BCC) DEA Model

Another version of DEA that is in common use is the Banker, Charnes, and Cooper (BCC) (1984) model. The BCC model of Banker et al. (1984) is formulated similarly to that for the CCR model. Banker et al. (1984) presented the BCC model to determine whether there are any inefficiencies attributed to disadvantageous conditions under which a DMU is operating, which are not directly related to the inputs and outputs, and to allow for a larger peer group to be considered.

The primary difference between this model and the CCR model is the treatment of returns-to-scale. The CCR version bases the evaluation on constant returns-to-scale. The BCC version is more flexible and allows variable returns-to-scale (VRS).

If an increase in an unit's inputs does not produce a proportional change in its outputs then the unit exhibits VRS. This means that as the unit changes its scale of operations, its efficiency will either increase or decrease.

The VRS efficiency represents pure technical efficiency, that is, a measure of efficiency without scale efficiency. It is thus possible to decompose technical efficiency into pure technical efficiency and scale efficiency. A unit is "scale efficient" when its size of operation is optimal. If its size of operation is either reduced or increased its efficiency will drop. A scale efficient unit is operating at optimal returns to scale. Scale efficiency is calculated by dividing the technical efficiency (from the CCR model) to the pure technical efficiency (from the BCC model).

Following is the BCC formulation which is named as model 4:

$$\min \theta - \varepsilon \left[\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right] \tag{18}$$

s. t.

$$\theta x_{io} - \sum_{j=1}^{n} \lambda_j x_{ij} - s_i^- = 0 \tag{19}$$

$$y_{ro} = \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ \tag{20}$$

$$\sum \lambda_j = 1 \tag{21}$$

$$\lambda_j ,\ s_i^- ,\ s_r^+ \geq 0 , \tag{22}$$

i=1,......m,

r=1,......s,

j=1,......n,

The difference between the CCR model and the BCC model is that the λ_j s are now restricted to summing to one. This has the effect of removing the constraint in the CCR model that DMUs must be scale efficient. Consequently, the BCC model allows variable returns-to-scale and measures only technical efficiency for each DMU. That is, for a DMU to be considered as CCR efficient, it must be both scale and technical efficient. For a DMU to be considered BCC efficient, it only needs be technically efficient.

The separate evaluation of returns-to-scale in the BCC model is more evident in the dual of model 4, named as model 5, which can be written as follows:

$$\max \sum_{r=1}^{s} u_r y_{ro} - u_o \tag{23}$$

s. t.

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} - u_o \leq 0, \tag{24}$$

$$\sum_{i=1}^{m} v_i x_{io} = 1 \tag{25}$$

$$-u_r \leq -\varepsilon \tag{26}$$

$$-v_i \leq -\varepsilon \tag{27}$$

In this model, the u_o^* (the * indicates an optimal value determined via model 5 indicates the return to scale possibilities. An $u_o^* < 0$ implies local increasing returns-to-scale and $u_o^* = 0$, implies local constant returns-to-scale. Finally, an $u_o^* > 0$ implies local decreasing returns-to-scale. The CCR model simultaneously evaluates both technical and scale efficiency. The BCC model, however, separates the two types of inefficiencies in order to evaluate only technical inefficiencies in the envelopment model (model 4) and scale inefficiencies in the dual of model 4 (model 5).

A DMU is BCC-efficient if and only if the optimal value to the problem (BCC) equals one. Otherwise, the DMU is said to be BCC-inefficient (Yun et al. 2004).

It should be noted that the results of the CCR input-minimized or output-maximized formulations are the same, which is not the case in the BCC model. Thus, in the output-oriented BCC model, the formulation maximizes the outputs given the inputs and vice versa.

4.1.4. Graphical Illustration

DEA graphical illustration can be seen in Figure 4.1. It is a simple single output, single input illustration of the CCR and BCC versions of the DEA model. In Figure 4.1, the y axis is the values for an output, and the x axis is the values for an input. Points P1, P2, P3, P4, and P5 represent observed performance of organizations. The numbers in parentheses following the point designation denote the coordinates of each point.

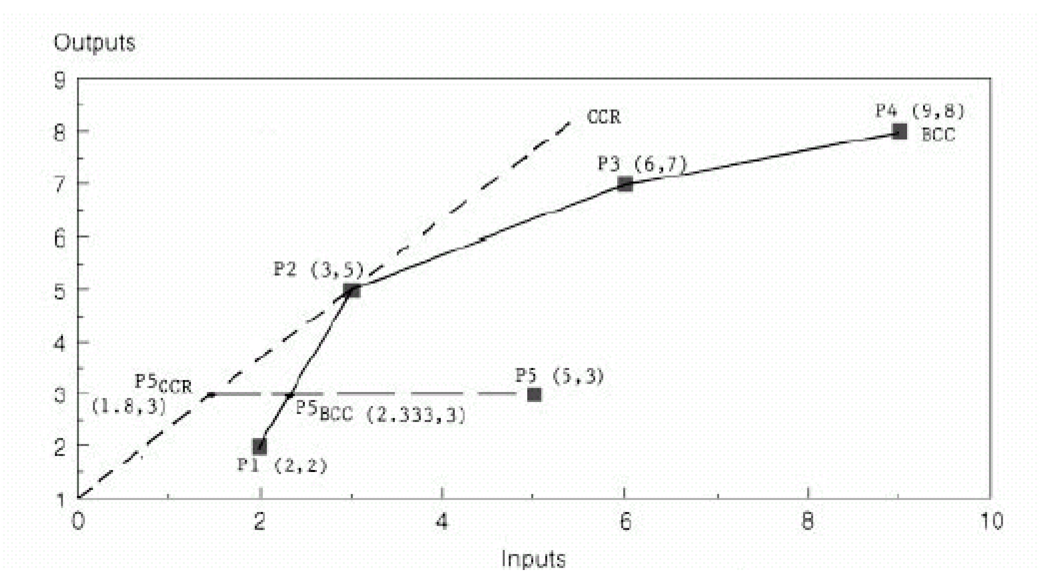


Figure 4.1 DEA graphical illustration (Bowlin, 1998)

The solid line, BCC, connecting P1, P2, P3, and P4 represents the frontier developed using the BCC DEA model. These organizations had the best-observed ratio of outputs to inputs. In the BCC version, P1, P2, P3, and P4 would be considered efficient and receive an efficiency rating of one, 1. These organizations are considered to be technically efficient.

However, this frontier reflects differing returns-to-scale. The segment P1-P2 reflects locally increasing returns-to-scale, i.e., an increase in the inputs would result in a greater than proportionate increase in output. That is, organization P1 is technically efficient and scale inefficient (not operating at constant returns-to-scale). P2 represents frontier operations at constant returns-to-scale and is, therefore, both technically and scale efficient. Segments P2-P3 and P3-P4 reflect locally decreasing returns-to-scale, i.e., an increase in inputs would result in a less than proportionate increase in output. Organizations P3 and P4 would also be technically efficient but scale inefficient.

The ray (dashed line) extending from the origin through P2 represents the efficiency frontier as determined by the CCR model. It reflects constant returns-to-scale. In the CCR version of the model, only P2 would be rated efficient since it is the only organization operating at constant returns-to-scale.

Differences between the CCR and BCC models can be further illustrated using organization (point) P5 in Figure 4.1. Using the BCC model, P5's rating would be based on its distance from $P5_{BCC}$, a linear combination of P1 and P2. P5 would receive an efficiency rating of 0.47, indicating that the organization's input should be reduced by 53% to 2.333 in order for it to be considered efficient.

Based on the CCR model, P5's rating would be determined by its distance from $P5_{CCR}$. P5 would receive an efficiency rating of 0.36 which indicates the organization would need to reduce its input by 64% to 1.8 in order to become efficient (both scale and technically efficient). It can be said that the rating provided via the BCC model will always be higher than the one provided by the CCR model (except in the case where an organization is rated efficient by both the CCR and BCC versions of the model as would be the case with P2).

Also, in the CCR case, organization P5 is moved to a frontier, which has constant returns-to-scale. This is what Banker (1984) refers to as most productive scale size (MPSS). MPSS of an efficient unit refers to the point (on the efficient frontier) at which maximum average productivity is achieved for a given input / output mix. At MPSS, constant returns to scale are operating. After reaching MPSS, decreasing returns to scale set in. In Figure 4.1, MPSS occurs at P2 (constant returns-to-scale). However, more generally MPSS will be a segment where the efficiency frontiers of the CCR and BCC models are tangential.

4.1.5. Strengths and Limitations

4.1.5.1. Strengths of DEA

The wide use of DEA as a powerful benchmarking tool can be attributed to:

- DEA can handle multiple input and multiple output models.

- DEA identifies possible peers as role models who have an efficiency of 1 and sets improvement targets for them.

- By providing improvement targets, DEA acts as an important tool for benchmarking.

- Possible sources of inefficiency can be determined using DEA (Govindarajan, 2003).

- It doesn't require an assumption of a functional form relating inputs to outputs.

- DMUs are directly compared against a peer or combination of peers.

• Inputs and outputs can have very different units. For example, X_1 could be in units of lives saved and X_2 could be in units of dollars without requiring a priori tradeoff between the two (Anderson, 1996).

4.1.5.2. Limitations of DEA

These characteristics that make DEA a powerful tool can also create problems. An analyst should keep following limitations in mind when choosing whether or not to use DEA:

• Being a deterministic rather than statistical technique, DEA produces results that are particularly sensitive to measurement error. If one organization's inputs are understated or its outputs overstated, then that organization can become an outlier that significantly distorts the shape of the frontier and reduces the efficiency scores of nearby organizations.

• DEA scores are sensitive to input and output specification and the size of the sample. Increasing the sample size will tend to reduce the average efficiency score, because including more organizations provides greater scope for DEA to find similar comparison partners. Conversely, including too few organizations relative to the number of outputs and inputs can artificially inflate the efficiency scores.

• Since a standard formulation of DEA creates a separate linear program for each DMU, large problems can be computationally intensive (Govindarajan, 2003).

• Since DEA is an extreme point technique, noise (even symmetrical noise with zero mean) such as measurement error can cause significant problems.

• DEA is good at estimating "relative" efficiency of a DMU but it converges very slowly to "absolute" efficiency. In other words, it can tell you how well you are doing compared to your peers but not compared to a "theoretical maximum".

• Since DEA is a non-parametric technique, statistical hypothesis tests are difficult and are the focus of ongoing research (Anderson, 1996).

4.2. Analytical Hierarchy Process

4.2.1. Definition

The Analytical Hierarchy Process (AHP), developed by Thomas L. Saaty, is a systematic procedure for representing the elements of any problem in the form of a hierarchy (Saaty & Kearns, 1985). Generally, the hierarchy has at least three levels: the goal, the criteria, and the alternatives. AHP is designed to solve complex decision problems involving both qualitative and also quantitative criteria.

This method aims at quantifying relative priorities for the alternatives on a ratio scale, based on the judgment of the decision-maker, and stresses the importance of the intuitive judgments of a decision-maker as well as the consistency of the comparison of alternatives in the decision-making process (Saaty, 1980). Since a decision-maker bases judgments on knowledge and experience, then makes decisions accordingly, the AHP approach agrees well with the behavior of a decision-maker (Al-Harbi, 2001).

AHP is one of the most popular multiple-criteria decision-making tools for formulating and analyzing decisions. The technique is employed for ranking the alternatives and then selecting the best in a set of alternatives. The ranking/selection is done with respect to an overall goal, which is broken down into a set of criteria (Ramanathan, 2004).

AHP is a robust technique that allows managers to determine preferences of criteria for selection purposes, quantify those preferences, and then aggregate them across diverse criteria (Onesime et al., 2004).

4.2.2. Application Areas Of AHP

AHP is a theory of measurement for dealing with quantifiable and intangible criteria that has been applied to numerous areas, such as decision theory and conflict resolution (Vargas, 1990).

AHP has been applied to measure performances of productive systems (Rangone, 1996), to the ABC classification of warehouse items (Partovi & Burton, 1993), to strategic planning (Armel & Orgler, 1990), to evaluate priorities in customers' needs (Armacost et al., 1994) and to investment analysis in innovative technologies (Stout, 1991; Weber, 1993; Wicks & Boucher, 1993).

Elkarmi & Mustafa (1993) used AHP to select best policies for increasing the utilization of solar energy technologies in Jordan. Mustafa & Ryan (1990) used AHP as a decision supports system for bid evaluation. Eddi & Hang (2001) discussed the applications of AHP for measuring business performance. Tiwari & Banerjee (2001) proposed the use of AHP as a decision support system for the selection of a casting process. Kamal (2001) used AHP to select the most suitable contractor in the prequalification process of a project. Chandra & Schall, (1988) used AHP for the economic evaluation of flexible manufacturing system using the Leontif input–output model. Narasimhan (1983) proposed the use of the AHP to deal with imprecision in supplier selection.

In this thesis, AHP is used to obtain the priorities of suppliers and distributors in designing a supply chain. For this purpose, first, suppliers of each material type and distributors of each distribution region are selected by Data Envelopment Analysis. These selected suppliers send supplying units to manufacturers and manufacturers send finished products to selected distributors. And then the priorities for the selected suppliers and distributors are determined using by AHP. Priorities are used to obtain which one of the selected suppliers will be used firstly and which one of the selected distributors will be used firstly. Quantities of supplying units and finished products are determined using by transportation model.

4.2.3. AHP Principles

The AHP is based on three principles or steps: The first step is decomposition, structuring of the decision problem into a hierarchical model. Second step is performing comparative judgments, and the third step is the synthesis of priorities of the elements (Saaty, 1983). The AHP attempts to estimate the impact of each of the alternatives on the overall objective of the hierarchy by implementing these three steps (Kablan, 2004).

The first step includes decomposition of the decision problem into elements according to their common characteristics and also it includes the formation of a hierarchical model having different levels (Zahedi, 1986). The AHP starts by decomposing a complex, multi-criteria problem into a hierarchy of goal, criteria, and alternatives where each level consists of a few manageable elements which are then decomposed into another set of elements (Wind & Saaty, 1980).

A simple AHP model can be seen in Figure 4.2 that has three levels (goal, criteria and alternatives). Four criteria are represented as C_1, C_2, C_3, and C_4, three alternatives are represented as A_1, A_2 and A_3. Though the simple model with three levels shown in Figure 4.2, this is the most common AHP model, more complex models containing more than three levels are also used in the literature. Criteria can be divided further into sub-criteria and these sub-criteria are divided into sub-sub-criteria. Finally alternatives take place in the last level of the hierarchy (Ramanathan, 2004). The hierarchical design given in Figure 4.2 can help the decision maker (DM) understand the problem better as to the importance of each level of the decision problem (Setiawan, 2002).

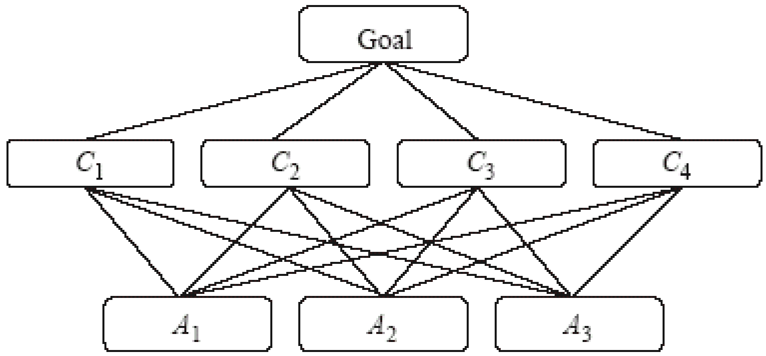


Figure 4.2. A simple AHP model (Ramanathan, 2004).

The second step involves using a measurement methodology to establish priorities among the elements within each level of the hierarchy. The priorities are derived by a pairwise comparison of each set of elements with respect to each of the elements on a higher level (Wind & Saaty, 1980). A verbal or a corresponding 9-point numerical scale can be used for the comparisons which can be based on objective, quantitative data or subjective, qualitative judgments. Saaty has proposed a numerical scale to represent the degree of "importance" of one alternative (or criterion) compared with another. The scale consists of the discrete numbers in the set of {1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2, 1, 2, 3, 4, 5, 6, 7, 8, 9}. The explanation of these values is given in Table 4.1. Usually, an element receiving higher rating is viewed as superior (or more attractive) compared to another one that receives a lower rating (Saaty, 1980).

This scale is widely accepted in the decision-making community, mostly in the AHP context, due to its support by a psychological study which stated that a person cannot compare more than seven entities (plus or minus two) at the same time (Miller, 1956). Using this scale, the decision maker can express his/her opinion on the importance of an alternative or criterion compared to an another alternative or criterion. In order to ensure consistency, the comparisons of the alternatives must be based on a common criterion at a time.

Table 4.1 Saaty's scale of preferences in the pair-wise comparison process (Saaty, 1980)

Numerical Value	Linguistic Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favor one activity over another
5	Strong Importance	Experience and judgment strongly favor one activity over another
7	Very Strong or Demonstrated Importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate Values	To reflect the compromise between two adjacent judgments

The third step involves using the AHP to vertically synthesis the priorities of the elements so that the overall priorities for the decision alternatives can be established. The calculation of the priorities is introduced in detail in AHP methodology section.

4.2.4. Strenghts And Limitations

4.2.4.1. Strengths of AHP

AHP is one of the most widely used decision analysis methods. Its main advantages are:

- AHP is a relatively easy approach to understand and apply (Onesime et al., 2004).

AHP enables the decision-makers to take into account both qualitative and quantitative factors and to use both objective and subjective judgments in the decision process (Kyläheiko et al, 2002). It does not require decision makers to make numerical guesses, as subjective judgments are easily included in the process and the judgments can be made entirely in a verbal mode (Forman, 1985).

- AHP can take into account the human knowledge and experience during the decision-making process with the importance weightings assignment (Chan F.T.S. et al., 2005). It examines the problem by considering the opinions of different socio-economical individuals that gives different weights to different criteria (Caliskan, 2005).

- By breaking a problem down in a logical fashion from the large, descending in gradual steps, to the smaller and smaller, one is able to connect, through simple paired comparison judgments, the small level to the large one (Al-Harbi, 2001).

- There is no need to openly establish a benefit function (Ulengin, 1992).

- AHP provides the simple representation of a multi-criteria problem by comparing multiple alternatives in the form of a pairwise comparison matrix (Setiawan, 2002).

- The flexibility of the AHP allows the decision makers to make the decision hierarchies to match exactly the requirements of the decision process they are facing (Kyläheiko et al., 2002).

- AHP can accommodate uncertain information and allows the application of insight, and intuition in a logical manner (Bello, 2003).

4.2.4.2. Limitations Of AHP

Despite its popularity, some shortcomings of AHP have been reported as below, which have limited its applicability.

- AHP only considers a one-way hierarchical relationship among factors (Onesime et al., 2004).

- The number of judgments to be elicited in AHP increases as the number of alternatives and criteria increase. This is often a tiresome and exerting exercise for DM (Ramanathan, 2004).

- The issue of rank reversal is one of the prominent limitations of traditional AHP (Belton & Gear, 1983). The ranking of alternatives determined by the traditional AHP may be altered by the addition or deletion of another alternative for consideration. For example, when a new alternative is added to the list of alternatives, or when an existing alternative is removed, it is possible that their rankings change. This has been a point of many debates as a theoretical and practical limitation of AHP (Dyer, 1990).

4.2.5. Group Decision Making

AHP is designed for complex decision problems and judging from the numerous case studies in the literature, it appears to be a popular tool for decision support. Several contributions also extend the AHP to group decision making and conflict resolution (Chwolka & Raith, 2001).

AHP allows group decision making, where group members can use their experience, values and knowledge to break down a problem into a hierarchy and solve it by the AHP steps. Brainstorming and sharing ideas and insights often lead to a more complete representation and understanding of the issues (Al-Harbi, 2001).

In a group decision making, there are several ways of including the views and judgments of each person in the priority setting process. In the common objectives context where all members of the group have the same objectives, there are four ways that can be used for setting the priorities: (1) consensus, (2) vote or compromise, (3) geometric mean of the individuals' judgments, and (4) separate models or players (Dyer & Forman, 1992).

Saaty (1982) stated that AHP forms a systematic framework for group interaction and group decision making. Dyer & Forman (1992) described the advantages of AHP in a group setting as follows:

1. Not only tangibles and intangibles, but also individual values and shared values can be included in an AHP-based group decision process,

2. The discussion in a group can be focused on objectives rather than on alternatives,

3. The discussion can be structured so that every factor relevant to the decision is considered in turn,

4. In a structured analysis, the discussion continues until all relevant information from each individual member in the group has been considered and a consensus choice of the decision alternative is achieved.

In this thesis, group decision making is used to obtain priorities of selected suppliers, according to predetermined criteria.

4.2.6. AHP Methodology

AHP is based on a firm theoretical foundation. The basic theory of AHP may be simplified as in the following (Saaty, 1980; Golden et al., 1989; Saaty, 1990): There are n different and independent alternatives (A_1,A_2,........,A_n) and they have the weights (W_1, W_2,........, W_n) respectively. The DM does not know in advance the values of W_i, i=1,2,.....n, but DM is capable of making pair-wise comparison between the different alternatives. Also, it is assumed that the quantified judgments provided by the DM on pairs of alternatives (A_i, A_j) are represented in an n x n matrix as in the following (Kablan, 2004):

$$A = \begin{array}{c} \\ A_1 \\ A_2 \\ . \\ . \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & \ldots & A_n \end{array} \\ \begin{pmatrix} a_{11} & a_{12} & \ldots & a_{1n} \\ a_{21} & a_{22} & \ldots & a_{2n} \\ . & . & \ldots & . \\ . & . & \ldots & . \\ a_{n1} & a_{n2} & \ldots & a_{nn} \end{pmatrix} \end{array} \qquad (28)$$

$a_{i,j}$ ($a_{i,j} > 0$) reflects the value of how "important" alternative i is when it is compared to alternative j. If for example the DM compares alternatives A_1 with alternative A_2, he provides a numerical value judgment a_{12} which should represent the importance intensity of alternative A_1 over alternative A_2. The a_{12} value is supposed to be an approximation of the relative importance of A_1 to A_2, i.e., $a_{12} \approx (W_1 / W_2)$. This can be generalized and the following can be concluded :

1. $a_{ij} \approx W_i / W_j$ i,j = 1,2,.....,n.
2. $a_{ii} = 1$, i = 1,2,.....,n.
3. If $a_{ij} = \alpha$, $\alpha \neq 0$ then $a_{ji} = 1 / \alpha$, i = 1,2,....,n.
4. If A_i is more important than A_j then $a_{ij} \approx (W_i / W_j) > 1$.

Obviously, it can be assumed that the following statements are true: $a_{i,j} = 1/a_{j,i}$ for all i,j = 1, …, n (third item in the above list) and the diagonal entries are equal to 1. That is, $a_{i,i} = 1$, for all i = 1, …, n (second item in the above list).

This implies that matrix A should be a positive and reciprocal matrix with 1's in the main diagonal and hence the DM needs only to provide value judgments in the upper triangle of the matrix. The values assigned to a_{ij} according to Saaty scale are usually in the interval of 1–9 or their reciprocals. Table 4.1 presents Saaty's scale of preferences in the pair-wise comparison process. It can be shown that the number of judgments (L) needed in the upper triangle of the matrix are:

$$L = n\,(n-1)/2, \qquad (29)$$

where n is the size of the matrix A (the number of alternatives (or criteria) to be compared).

The next step is to recover the numerical weights (W_1, W_2,........, W_n) of the alternatives using the numerical judgments a_{ij} in the matrix A:

$$\begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & . & \dots & . \\ . & . & \dots & . \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix} \approx \begin{pmatrix} W_1/W_1 & W_1/W_2 & \dots\dots & W_1/W_n \\ W_2/W_1 & W_2/W_2 & \dots\dots & W_2/W_n \\ . & . & \dots\dots & . \\ . & . & \dots\dots & . \\ W_n/W_1 & W_n/W_2 & \dots\dots & W_n/W_n \end{pmatrix} \qquad (30)$$

The matrices given in (30) are multiplied on the right with the weights vector $W=(W_1,W_2,........,W_n)$, where W is a column vector. The result of the multiplication of the matrix of pair-wise ratios with W is nW; hence it follows:

$$AW = nW \qquad (31)$$

This is a system of homogenous linear equations. It has a non-trivial solution if and only if the determinant of A-nI vanishes, that is, n is an eigenvalue of A. I is an n x n identity matrix. Saaty's method computes W as the principal right eigenvector of the matrix A, that is,

$$AW = \lambda_{max}\,W \qquad (32)$$

where λ_{max} is the principal eigenvalue of the matrix A. If matrix A is a positive reciprocal one then $\lambda_{max} \geq n$, (Saaty, 1980).

The judgments of the DM are perfectly consistent as long as

$$a_{ij} * a_{jk} = a_{ik}, \qquad i, j, k = 1,2,.....n, \tag{33}$$

which is equivalent to

$$(W_i / W_j)\ (W_j / W_k) = (W_i / W_k), \tag{34}$$

$a_{i,k}$ is the comparison of alternative i with alternative k, more appropriately, the ratio of the relative weights of alternative i to alternative k in terms of a single criterion. For example, if any criterion A compared to criterion B has a numerical rating of 3 and if criterion B compared to criterion C has a numerical rating of 2, perfect consistency of criterion A compared to criterion C would have a numerical rating of 3 * 2 = 6. If A to C numerical rating assigned by the DM was 4 or 5, some inconsistency would exist among the pairwise comparison.

The eigenvector method yields a natural measure of consistency. Saaty defined the consistency index (CI) as

$$CI = (\lambda_{max} - n) / (n - 1) \tag{35}$$

For each size of matrix n; random matrices were generated and their mean CI value, called the random index (RI), was computed and tabulated as shown in Table 4.2. Accordingly, Saaty defined the consistency ratio as

$$CR = CI / RI. \tag{36}$$

Table 4.2 Average random index for corresponding matrix size (Saaty, 1980)

Matrix size (n)	1	2	3	4	5	6	7	8	9	10
Random index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The consistency ratio (CR) is a measure of how a given matrix compares to a purely random matrix in terms of their consistency indices. A value of the consistency ratio CR $\leq$ 10% is considered acceptable. Larger values of CR require the DM to revise his judgments. Saaty proposed the following steps for the application of the AHP (Saaty, 1980):

1. State the overall objective of the problem and identify the criteria that influence the overall objective.

2. Structure the problem as a hierarchy of goal, criteria, sub-criteria, and alternatives.

3. Start by the second level of the hierarchy:

- Do pair-wise comparison of all elements in the second level and enter the judgments in an n x n matrix.

- Calculate priorities by normalizing the vector in each column of the matrix of judgments and averaging over the rows of the resulting matrix and you have the priority vector.

- Compute the consistency ratio of the matrix of judgments to make sure that the judgments are consistent.

4. Repeat step 3 for all elements in a succeeding level but with respect to each criterion in the preceding level.

5. Synthesize the local priorities over the hierarchy to get an overall priority for each alternative.

CHAPTER FIVE
TRANSPORTATION AND TRANSSHIPMENT PROBLEMS

5.1. The Transportation Problem

Fierce competition in today's global market, the introduction of products with short life cycles, and the heightened expectations of customers have forced business enterprises to focus attention on their supply chains. The efficient movement and timely availability of raw materials and finished goods in a cost-effective manner becomes a challenge. Transportation models provide a powerful framework to meet this challenge (Liu, 2003).

The transportation problem arises frequently in planning for the distribution of goods and services from several supply locations to several demand locations. Typically, the quantity of goods available at each supply location (origin) is limited, and the quantity of goods needed at each of several demand locations (destinations) is known. The usual objective in a transportation problem is to minimize the cost of shipping goods from the origins to the destinations (Anderson et al., 2004).

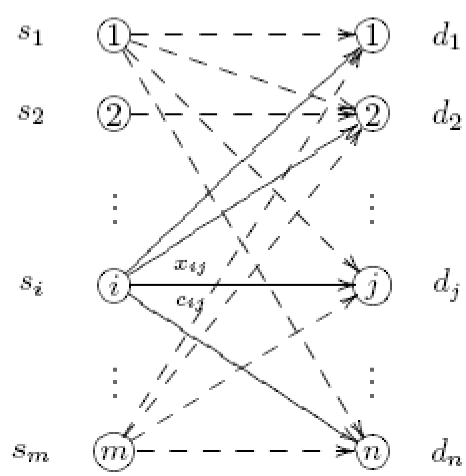


Figure 5.1 Network representation of the transportation problem (Wei, 2004)

The network representation for a transportation problem can be seen in Figure 5.1. s_i denotes the sources (origin) and d_j denotes destinations.

The rest of this chapter is organized as follows: In section 5.2, a brief definition of transshipment problem is included and the literature survey is given in section 5.3. In the section 5.4, the mathematical models for the transportation and the transshipment problems are formulated. In section 5.5, the solution procedures for the transportation and transshipment problems are given. Finally, the advantages of the transportation and transshipment models are given in section 5.6.

5.2. The Transshipment Problem

The transshipment problem is an extension of the transportation problem in which intermediate nodes, referred to as transshipment nodes, are added to account for locations such as warehouses. In this more general type of distribution problem, shipments may be made between any pair of the three general types of nodes: origin nodes, transshipment nodes, and destination nodes. For example: the transshipment problem permits shipments of goods from origins to intermediate nodes and on to destinations, from one origin to another origin, from one intermediate location to another, from one destination location to another, and directly from origins to destinations.

The supply available at each origin is limited, and the demand of each destination is specified like as the transportation problem. The objective in the transshipment problem is to determine how many units should be shipped over each shipment in the network so that all destination demands are satisfied with the minimum possible transportation cost (Anderson et al., 2004).

5.3. Literature Survey

The transportation problem, which was first studied by Hitchcock FL. in 1941, is a well-known problem that can be formulated and solved as a linear program. There has been a sizable amount of work done on transportation and transshipment problems.

There exists a rich literature on formal models of transshipment, which begins with Krishnan & Rao (1965). These two authors studied a general number of retailers with centralized control and independent demands, where transshipments can be made at some cost after observing demand, but before having to satisfy it. Further, they showed that it is optimal for the retailers to stock at an equal fractile. The model framework of Krishnan & Rao appears to be the most commonly used one, including work by Tagaras (1989), Robinson (1990), Herer & Rashit (1999), and Herer et al. (2001). Tagaras (1989) extended Krishnan and Rao's model by examining a two-location problem where cost parameters varied from facility to facility. He also established the conditions for complete inventory pooling. Robinson (1990) discussed solution techniques for specific cases of these types of problems over multiple periods.

The problems, where transshipments occur before demand is realized, are also considered by many authors. Gross (1963) conducted the preliminary research in this area, discussing the optimal stocking/shipment policies when transshipment decisions must be made before demand for that period is realized. Das (1975) extended that model by allowing transshipments to occur both before and after demands were realized. In another study, Hoadley & Heyman (1977) examined a one period model that incorporated the transshipments from the warehouse before demand was realized, and the transshipments after demand was realized. The Hoadley and Heyman model also allowed facilities to return excess stock (at a cost).

Numerous papers have been written analyzing solution techniques and computational results for various transportation and transshipment problems. Charnes & Copper (1954) developed the stepping stone method, which provided an alternative way of determining the simplex method information. Likewise, Dantzig (1963) applied the simplex method to the transportation problem as the primal simplex transportation method.

In another study, Karmarkar & Patel (1977) considered the single period transshipment problem, and later Karmarkar (1987) extended the analysis for multiperiod problems. Transshipment problem has also been studied using simulation and stochastic programming techniques so that upper and lower bounds or solutions are found to these problems.

Arsham & Khan (1989) also proposed a new algorithm for solving transportation problem. Arsham (1992) applied perturbation analysis to postoptimality analyses of the transportation problem. In a recent study, Adlakha & Kowalski (1998) provided candidate locations for more-for-less solution in the transportation problem.

5.4. Mathematical Models

5.4.1. Mathematical Model For The Transportation Problem

In a conventional transportation problem, a homogeneous product is to be transported from several origins to several destinations in such a way that the total transportation cost is minimum. Suppose that there are m supply nodes and n demand nodes. The i th supply node can provide s_i units of a certain product and the j th demand node has a demand for d_j units. The transportation of products from the i th supply node to the j th demand node carries a cost of c_{ij} per unit of product transported. The problem is to determine a feasible way of transporting the available amounts to satisfy the demand so that the total transportation cost can be minimized (Liu, 2003).

The mathematical description of the conventional transportation problem is as follows (Liu, 2003):

$$\min \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}\, x_{ij} \qquad (1)$$

s. t.

$$\sum_{j=1}^{n} x_{ij} \leq s_i \quad , i=1,\ldots,m, \text{ Supply} \tag{2}$$

$$\sum_{i=1}^{m} x_{ij} = d_j \quad , j=1,\ldots,n, \text{ Demand} \tag{3}$$

$$x_{ij} \geq 0 \qquad \forall i,j, \tag{4}$$

where

x_{ij} is the number of units shipped from origin i to destination j;

c_{ij} is the cost per unit of shipping from origin i to destination j;

s_i is supply or capacity in units at origin i;

d_j is demand in units of destination j;

m is the number of origins;

n is the number of destinations.

The objective function (1) aims at minimizing the number of units to be shipped from supply nodes to demand nodes by taking into account the transportation costs.

Constraint (2) states that the sum of the shipments from a source cannot exceed the supply of this source.

Constraint (3) states that the sum of the shipments to a destination is equal to the demand of this destination.

Constraint (4) is the nonnegativity constraint on the x_{ij}'s.

The above problem implies that the total supply ($\sum s_i$) must be at least the total demand ($\sum d_j$).

In reality, many transportation problems will not have equal supply and demand. In most situations supply will exceed demand but the opposite can also occur. However this unbalance between supply and demand is not a problem in using the transportation technique. Problem is balanced with adding a dummy source or destination. If the demand is greater than the supply, a dummy source is introduced. If the supply is greater than the demand, a dummy destination is introduced. As no transportation cost is incurred if goods are not shipped, 0 is allocated to the cells in the dummy source or destination as cost.

5.4.2. Mathematical Model For The Transshipment Problem

The mathematical description of the conventional transshipment problem is given as follows (Anderson et al., 2004).

$$\min \sum_{\text{all arcs}} c_{ij}\, x_{ij} \tag{5}$$

s. t.

$$\sum_{\text{arcs out}} x_{ij} - \sum_{\text{arcs in}} x_{ij} \le s_i \text{, Origin nodes } i \tag{6}$$

$$\sum_{\text{arcs out}} x_{ij} - \sum_{\text{arcs in}} x_{ij} = 0 \text{, Transshipment nodes } i \tag{7}$$

$$\sum_{\text{arcs in}} x_{ij} - \sum_{\text{arcs out}} x_{ij} = d_j \text{, Destination nodes } j \tag{8}$$

$$x_{ij} \ge 0 \qquad \forall i,j, \tag{9}$$

where

x_{ij} = number of units shipped from node i to node j,

c_{ij} = cost per unit of shipping from node i to node j,

s_i = supply at origin node i,

d_j = demand of destination node j.

The objective function (5) aims at minimizing the total transshipment cost.

Constraint (6) states that the total shipment from an origin node not exceed that the capacity of this origin node.

Constraint (7) states that the total amount of units shipped to a transshipment node exactly equal to the total amount of units shipped from this transshipment node.

Constraint (8) states that the total amount of units shipped to a destination node is equal to the demand of this destination node.

Constraint (9) is the nonnegativity constraint on the x_{ij}'s.

5.5. The Solution Procedures For The Transportation And Transshipment Problems

Transportation and transshipment models do not start at the origin where all decision values are zero; they must instead be given an initial feasible solution. That solution is then tested to see if it is optimal. If it is not optimal, further feasible solutions are generated until the optimal solution (if it exists) is identified. This is what the simplex algorithm accomplishes in an efficient manner. Initial solution methods for transportation and transshipment problems are:

1. The North West Corner (NWC) Method.

2. The Low Cost Cell (LCC) Method.

3. Vogel's Approximation Method (VAM).

Methods to obtain a final solution for transportation and transshipment problems are: (Transportation and transhipment problems, n.d.).

1. The Stepping Stone Method
2. The Modified Distribution Method (MODI)

5.6. Advantages Of The Transportation And Transshipment Models

Advantages of the transportation and transshipment models can be listed as follows (Transhipment & routing problems, n.d.):

- Provides logistics management

Logistics management became very important in the recent times primarily due to two factors. The first one is the transportation cost involved in shipping the goods from sources to destination are witnessing a continuous increase. Secondly, the company's customers are scattered geographically over large territories. Since it is not possible to effectively cater to the peculiar market demands of a central distribution point, transshipment models provide a cost-effective solution to the transportation requirements of the organizations.

- Provides optimum distribution-channels

Based on the peculiarities of different types of business situations, transshipment models provide an optimum distribution network for the company's products by carefully examining the demand and supply patterns required to be maintained to effectively service the customer.

- Increases customer base

Transshipment models help a company in increasing its customers base by marking the products available in different markets at the desired point of time & minimizing the over all transportation costs that are required to be necessarily incurred. Hence, it expands the over all customer base by taking care of their re-purchase mods.

- Resources management

Even a large corporation faces the problem of scarcity of resources, which must optimally be managed to endure its profitability and the overall growth. Transshipment models, when used efficiently, allow the management to allocate the resources to the critical areas.

- Reduces stock-out costs

The transshipment problems give the best possible solution for the problem of maintenance of the right quantity of company's products at various locations or markets with a proper evaluation of the supply and demand characteristics of a particular market.

- Prevents over stocking

By focusing primarily on the demand forecasts, the transshipment models enable the management in arriving at the adequate level of stocks to be maintained, so that an excessive amount of working capital is not blocked unnecessarily in the diverse inventory items.

In this thesis, the transportation problems for the raw materials and finished products are solved using by the transportation model. First model determines optimal routing and quantities of raw materials for each material type, which are sent from selected suppliers to three manufacturers, by taking into consideration the annual production capacities and priorities of the selected suppliers and also the demand of three manufacturers. Second model determines optimal routing and quantities of finished products for each distribution region, which are sent from three manufacturers to selected distributors, by taking into consideration the annual production capacities of three manufacturers, priorities and the demand of the selected distributors.

CHAPTER SIX
DESIGNING A SUPPLY CHAIN NETWORK FOR AN AUTOMOTIVE COMPANY

6.1. Introduction

Increasing competitive pressures are forcing companies to increase their rates of innovation. The increasing rate of innovation shortens each product's duration in the market, thereby compressing each product's life cycle. Without proper management, increasing product turnover will increase design and manufacturing costs. More frequent product development cycles require additional product development resources. Likewise, shorter production runs inhibit a company's ability to achieve manufacturing cost reductions by exploiting the learning curve and scale economies.

Focusing on supply chain network (SCN) design is one way companies can combat the problems caused by increased competition. The SCN design involves the selection of competent and compatible partners, that design, produce, and distribute the product, network operation includes exact sourcing and deployment plans. SCNs are considered as a solution for effectively meeting customer requirements such as low costs, high product variety, high quality, and short lead times. However, the success of SCNs depends to a large extent on how effectively they are designed and operated.

There are many strategic, tactical, and operational aspects that must be considered in designing and operating SCNs. Strategic issues in supply chain network design are anticipatory, i.e. they best prepare the supply chain to meet risk and uncertainty. Strategic issues are related to supplier and distributor selection, facility location, production and inventory decisions. The operational issues in supply chain network design focus on activities over a day-to-day basis. They involve activities like production planning, emergency measures, production scheduling in different production sites, storage scheduling within warehouses etc.

This thesis has been carried out at an automotive company, which produces a wide variety of heavy, medium and light commercial vehicles, pick-ups, minibuses, panel vans, military vehicles, buses and special purpose vehicles, tractor heads, loose engines and various spare parts in three different plants located in İzmir.

This study primarily focuses on strategic issues in SCN design including supplier and distributor selection and also some operational issues that involve sourcing and deployment plans. The rest of the thesis is organized as follows: In section 6.2, the current literature related to the design of SCNs is presented. In section 6.3, we discuss the methodology employed in designing a SCN for the automotive company. The steps of this methodology are illustrated in section 6.4. The study ends with concluding remarks in section 6.5.

6.1. Literature Survey

The studies emphasizing SCN development can be categorized into conceptual and quantitative frameworks. The first study in the area of conceptual network models was carried out by Miles and Snow (1984). They introduced the concept dynamic networks, which are formed by a group of independent companies. The lead firm in this network identifies potential partners who own a large or sometimes the entire portion of the assets in the SCN. The application of dynamic networks in private and public industries was studied by Lawless and Moore (1989). Managerial processes for designing, operating, and care-taking a network were suggested by Snow et al. (1992) and Snow and Thomas (1992).

More recently the concept of virtual corporations was proposed. They are an alliance of independent business processes or enterprises with each contributing core competencies in areas such as design, manufacturing, and distribution to the network (Byrne, 1993; Goldman, 1994; Iacocca Institute, 1991; Porter, 1993; Presley et al., 1995; Sheridan, 1993).

It must be noted that the key issue in designing SCNs is the selection of highly efficient and compatible partners. Although several conceptual models for supply chains have been proposed and discussed in the literature, research efforts are lagging behind in the development of formal decision models for SCN design.

Studies in the development of quantitative frameworks for supply chain management (SCM) have mainly focussed on the tactical and operational levels rather than the strategic level. The initial mathematical work in this area was performed by Geoffrion and Graves (1974). They proposed a multicommodity logistics network design model for optimizing annualized finished product flows through the supply chain.

Later, Cohen and Lee (1985) proposed a pair of models for the network design problem, which is based on Geoffrion and Graves' (1974) work. They proposed a multicommodity manufacturing network design model that optimized the product flows from raw material vendors to end customers. In another paper, Cohen and Lee (1988) proposed a set of approximate stochastic sub-models and heuristic methods to develop stationary long-term operational policy for supply chains. Subsequently, Cohen and Lee (1989) proposed a deterministic model for a global manufacturing and distribution network. This model included value markups and costs, exchange effects, and before and after tax profitability estimation. All of these models concentrate more on the operational issues of SCN design.

More recently, Arntzen et al. (1995) presented a global supply chain model for designing a production, distribution, and vendor network. In this study, they minimized production, inventory and distribution costs by using a mixed-integer linear program. However, this model does not consider efficiencies of SCN processes, and primarily addresses issues related to reengineering an existing supply chain.

Talluri et al. (1999) employed the basic Charnes, Cooper and Rhodes (CCR) (Charnes et al., 1978) model for efficiency evaluation and they identified a single best supplier – manufacturer combination. In a following study, (Talluri & Baker, 2002), besides dealing with strategic issues, the authors addressed operational aspects by incorporating capacity and location constraints into the decision making process. Moreover, they proposed a multi-phase mathematical programming approach to design the entire SCN with several nodes at each value-added stage.

In this thesis, a SCN is designed for a recently introduced product of an automotive company by integrating various approaches. The study has been carried out in two phases: The first phase, which is based on Talluri and Baker's study (2002), involves selecting suppliers and distributors by using Data Envelopment Analysis (DEA) and integer-programming model. It must be noted that addressing a real industrial problem in this study, the suppliers and distributors were selected for a given number of manufacturers. Following, we employed transportation models to identify the optimal quantity and routing decisions for supply of raw materials and distribution of finished products. Moreover, to reflect the preferences of the company on selected suppliers and distributors, we calculated a priority ranking for each using Analytical Hierarchy Process (AHP) and integrated these rankings into the transportation models.

6.3. Methodology For Designing A SCN

As mentioned earlier, a two-phase procedure is employed in designing a SCN. The first phase, which involves selecting suppliers and distributors, exclusively concentrates on the operating efficiencies of candidate suppliers and distributors. In other words, this phase addresses the SCN problem at the strategic level. The second phase deals with operational issues. Particularly, based on the given demand and capacity constraints of all network nodes, a transportation model is constructed to identify the optimal routing decisions.

6.3.1. Phase 1: Supplier And Distributor Selection

The first phase is carried out in three steps: First, the relative efficiency score for each candidate supplier and distributor is obtained by using the basic DEA model, the CCR model. As mentioned earlier, one of the limitations of the CCR model is unrestricted weight flexibility. To deal with this weight flexibility limitation, next the pair-wise efficiency game (PEG) model is employed to perform pair-wise comparisons. The outputs of CCR and PEG models are used to calculate an aggregated mean efficiency score for each candidate supplier and distributor. Lastly, an integer-programming model is constructed to optimally select the suppliers and distributors.

6.3.1.1. Step 1: Application of CCR Model

In this step, first the key input/output measures for candidate suppliers and distributors are identified and data on all these measures are collected. To calculate the relative efficiency score of each candidate supplier and distributor, next CCR model that allows for the incorporation of multiple inputs and outputs is utilized. It must be noted that the candidate suppliers and distributors were referred as decision-making units (DMUs) henceforth. For detailed information about CCR model, see section 4.1.3.1.

A conventional CCR model involves calculating the relative efficiency score of a DMU by assigning such weights to the inputs and outputs of that DMU so that the ratio of its weighted output to weighted input is maximized. Apart from the condition that the weights should be nonzero, the only other condition that restricts the weights is that the efficiency score of none of the DMUs should exceed unity. Thus, the CCR model in its purest form allows flexibility in the selection of weights, especially if fewer DMUs are included in the analysis (i.e., with fewer DMUs, there are more freedom to the weights). This is known as weight flexibility. The weight flexibility is often discussed as a main weakness of traditional CCR model.

Weight flexibility allows each DMU to achieve the maximum feasible efficiency score with its existing levels of inputs and outputs. An argument in favor of the weight flexibility is that if a DMU is identified as inefficient in spite of using a favorable set of weights, it is a strong statement about the inefficiency of that DMU.

Another argument in favor of the flexibility is that the efficiency of different DMUs is evaluated using different sets of weights allowing DMUs to express their different circumstances and different objectives.

Weight flexibility has numerous drawbacks. The salient drawbacks are:

- The efficiency score in DEA is derived relative to the performance of other DMUs and not to some ideal production frontier. As a result, a DMU that is superior to all other units in only a single output - input ratio will receive an efficiency score of one by placing very high weights on that particular output-input ratio. Thus, factors of secondary importance may dominate a DMU's efficiency assessment and some factors may be ignored. This may be unacceptable given the fact all factors are meticulously selected. In addition, the relative efficiency score of a DMU may not really reflect its performance with respect to the inputs and outputs taken as a whole. (Pedraja et al., 1997).

- Weight flexibility allows different DMUs to assign vastly different weights to the same factor. The argument in favor of this is that different DMUs have different circumstances and therefore one factor may be more important to one DMU compared to another DMU. Thus, some degree of weight flexibility may be desirable to allow DMUs to reflect their particular circumstances. However, complete flexibility becomes unacceptable as most of the DMUs employ similar technologies, pay similar prices for inputs, produce the same kind of outputs and have the same overall objectives (Pedraja et al., 1997).

So, the relative efficiency scores obtained from the CCR model may not accurately determine the performance of some DMUs because the input and output weights are unrestricted. That is a DMU can place maximum emphasis on relatively less number of input and output measures, and achieve a high efficiency score. So to deal with the unrestricted weight flexibility of the CCR model, in the second step, the pair-wise efficiency game formulation (PEG) model is used and a pair-wise comparison of DMUs is carried out.

6.3.1.2. Step 2: Pair-Wise Efficiency Game Formulation

This section explains the PEG formulation (Talluri, 2000), which is utilized in combination with the CCR model to carry out the pair-wise comparison of DMUs. Using the terminology of DEA, the unit whose efficiency is being evaluated is referred as the test DMU. A target DMU is the other DMUs that the test DMU is compared consecutively. In the following PEG model, the test DMU is represented as DMU_j and the target DMU is represented as DMU_o.

The following model compares the test DMU to a target DMU:

$\forall j \neq o, \quad j=1,......n.$

$$\min \left[\sum_{r=1}^{s} u_r y_{rj} \right] / \left[\sum_{i=1}^{m} v_i x_{ij} \right] \tag{1}$$

s.t.

$$\left[\sum_{r=1}^{s} u_r y_{ro} \right] / \left[\sum_{i=1}^{m} v_i x_{io} \right] = \theta, \tag{2}$$

$$\left[\sum_{r=1}^{s} u_r y_{rj} \right] / \left[\sum_{i=1}^{m} v_i x_{ij} \right] \leq 1, \tag{3}$$

$$u_r, v_i \geq 0 , \forall r, i, \tag{4}$$

where

θ is the efficiency score of target DMU obtained from the CCR model;

n is the number of DMUs;

s is the number of outputs;

m is the number of inputs.

$\mathbf{y_{rj}}$ is the amount of output r produced by DMU_j;

$\mathbf{y_{ro}}$ is the amount of output r produced by the target DMU (DMU_o);

$\mathbf{x_{ij}}$ is the amount of input i used by DMU_j;

$\mathbf{x_{io}}$ is the amount of input i utilized by the target DMU (DMU_o);

$\mathbf{u_r}$ is the weight given to output r;

$\mathbf{v_i}$ is the weight given to input i;

The objective function of the PEG formulation tries to minimize the ratio of the total weighted output to the total weighted input, that gives the efficiency score of a test DMU.

Constraint (2) prevents the efficiency score of the target DMU (DMU_o) from being either higher or lower than the DMU_o's maximum value, which is the CCR score.

Constraint (3) is a normalization constraint that prevents the efficiency score of the test DMU from exceeding a value of 1.

To convert the above non-linear problem into a linear program, the following transformation is carried out:

$$\sum_{i=1}^{m} v_i x_{ij} = 1 \qquad (5)$$

The above function represents that the weighted input of the test DMU in the objective function is equal to 1. The two original constraints of general formulation are transformed into linear constraints. The new formulation named as "model 1" is as follows:

$\forall j \neq o,$

$$\min \left[\sum_{r=1}^{s} u_r y_{rj} \right] \quad (6)$$

s.t.

$$\sum_{i=1}^{m} v_i x_{ij} = 1 \quad (7)$$

$$\sum_{r=1}^{s} u_r y_{ro} - \theta \sum_{i=1}^{m} v_i x_{io} = 0 \quad (8)$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \quad (9)$$

$$u_r, v_i \geq 0 \text{ , } \forall r, i. \quad (10)$$

By changing the target DMU, the PEG formulation is rerun "n-1" times, which results in exactly "n-1" efficiency scores for each DMU.

In the PEG model, the optimal weights of a target DMU may vary depending on the competitor being evaluated. The model emphasizes the target DMU's strengths, which are weaknesses of a test DMU. For example, consider a scenario where three

DMUs 1, 2 and 3 are being evaluated with respect to two inputs (I_1 and I_2) and two outputs (O_1 and O_2). Assume that DMU_1 is only performing well with respect to I_1 and O_1, DMU_2 is only performing well with respect to I_2 and O_2, and DMU_3 is performing well with respect to both inputs and both outputs. In the PEG formulation, when DMU_3 is the target DMU and DMU_1 is the test DMU, the model emphasizes the strengths of DMU_3 (I_2 and O_2) which are weaknesses of DMU_1 in dominating it. Similarly, when DMU_2 is the test DMU, the model emphasizes the strengths of DMU_3 (I_1 and O_1) which are weaknesses of DMU_2.

The results of PEG and CCR models are used to obtain an aggregated mean efficiency (M_EFF) score for each DMU. These aggregated mean efficiency scores are utilized as an index to differentiate between good and poor performers, where high score indicates good operating practices. If efficiency score of a test DMU that is obtained by PEG model is represented as $\mathbf{e_{jo}}$, an aggregated mean efficiency score for each DMU_j, M_EFF score is calculated as follows:

$$M\_EFF_j = \left(\sum_{o=1}^{n} e_{jo}\right) / n, \tag{11}$$

where
n is the number of DMUs.

For example if three DMUs are considered and the first DMU is accepted as the test DMU (j=1), then aggregated mean efficiency score calculations, M_EFF, for all DMUs will be as follows:

$M\_EFF_1 = (e_{11} + e_{12} + e_{13}) / 3,$
$M\_EFF_2 = (e_{21} + e_{22} + e_{23}) / 3,$
$M\_EFF_3 = (e_{31} + e_{32} + e_{33}) / 3,$

$\mathbf{e_{11}}$ is the CCR score for DMU_1, as a result of "j=o" in the above formulation.
$\mathbf{e_{12}}$ is the PEG score of DMU_1, when it is compared to DMU_2,

$\mathbf{e_{13}}$ is the PEG score of DMU_1, when it is compared to DMU_3.

As mentioned earlier, in addition to the CCR scores obtained for each DMU in the step 1, the PEG formulation generates exactly "n-1" efficiency scores for each DMU. The CCR and PEG models provide a productivity index that represents the efficiency of various DMUs based on multiple performance criteria. In summary, this step results in the aggregated mean efficiency score, M_EFF score, for each candidate supplier and distributor.

6.3.1.3. Step 3: Selection of Suppliers And Distributors

This step involves using the following integer-programming model, named as "model 2", to identify the optimal suppliers by taking into consideration the M_EFF score calculated above, and also the demand, capacity and location constraints:

$$\min \sum_{i=1}^{n} x_i \tag{12}$$

s.t.

$$\sum_{i=1}^{n} E_i x_i - E_{avg} \left(\sum_{i=1}^{n} x_i \right) \geq 0 , \tag{13}$$

$$\sum_{i=1}^{n} L_i x_i - L_{avg} \left(\sum_{i=1}^{n} x_i \right) \geq 0 , \tag{14}$$

$$\sum_{i=1}^{n} C_i x_i \geq \sum_{j=1}^{q} D_j , \tag{15}$$

$x_i = 0 \text{ or } 1,$ (16)

where

$\mathbf{x_i}$ is the binary variable that indicates the selection of supplier i;
n is the number of DMUs;
q is the number of manufacturers;
$\mathbf{E_i}$ is the M_EFF score of supplier i;
$\mathbf{E_{avg}}$ is “the required lowest M_EFF score”;
$\mathbf{L_i}$ is the location rating of supplier i;
$\mathbf{L_{avg}}$ is “the required lowest location rating”;
$\mathbf{C_i}$ is the annual production capacity of each supplier;
$\mathbf{D_j}$ is the demand of manufacturer j that must be satisfied.

The objective function (12) in the model 2 aims at minimizing the number of selected suppliers.

Constraint (13) states that the M_EFF score of selected supplier should be equal to or higher than the required lowest M_EFF score.

Constraint (14) states that the location rating of selected supplier should be equal to or higher than the required lowest location rating.

Constraint (15) states that the total capacity of selected suppliers should be equal to or higher than the total demand of three manufacturers.

Likewise, the following integer-programming model, named as “model 3”, is utilized to identify the optimal distributors:

$$\min \sum_{i=1}^{n} x_i \qquad (17)$$

s.t.

$$\sum_{i=1}^{n} E_i x_i - E_{avg} \left(\sum_{i=1}^{n} x_i \right) \geq 0 , \qquad (18)$$

$$\sum_{i=1}^{n} L_i x_i - L_{avg} \left(\sum_{i=1}^{n} x_i \right) \geq 0 , \qquad (19)$$

$$\sum_{i=1}^{n} D_i x_i \geq \sum_{j=1}^{q} C_j \qquad (20)$$

$$x_i = 0 \text{ or } 1, \qquad (21)$$

$i = 1,....,n,$
$j = 1,.....,q.$

where

$\mathbf{x_i}$ is the binary variable that indicates the selection of distributor i;

n is the number of DMUs;

q is the number of manufacturers;

$\mathbf{E_i}$ is the M_EFF score of distributor i;

$\mathbf{E_{avg}}$ is "the required lowest M_EFF score";

$\mathbf{L_i}$ is the location rating of distributor i;

$\mathbf{L_{avg}}$ is "the required lowest location rating";

$\mathbf{D_i}$ is the demand of distributor i that must be satisfied;

$\mathbf{C_j}$ is the annual production capacity of manufacturer j.

The objective function (17) in model 3 aims at minimizing the number of selected distributors.

Constraint (18) states that the M_EFF score of selected distributor should be equal to or higher than the required lowest M_EFF score.

Constraint (19) states that the location rating of selected distributor should be equal to or higher than the required lowest location rating.

Constraint (20) states that the degree of satisfying the demand of selected distributors will be limited by the capacity of the manufacturers.

6.3.2. Phase 2: Transportation From Suppliers To Manufacturers And From Manufacturers To Distributors

Phase 2 involves identifying optimal quantities and routing decisions for supply of raw materials and distribution of finished products by using transportation models. The first step of this phase involves setting priorities of selected suppliers and distributors, the second step involves the construction of transportation models to identify the optimal routing and the quantities to be transported. These two steps results in finding the values of the following decision variables:

1. The quantity of raw materials to be shipped from selected suppliers to three manufacturers,

2. The number of finished products to be shipped from three manufacturers to selected distributors.

6.3.2.1. Step 1: Determination Of The Priority Ranking Using AHP

This step involves analyzing the capabilities and characteristics of selected suppliers and distributors. A group, consisting 10 members of the company whose decisions are effective on management of the company, is required to evaluate the performances of selected suppliers and distributors. Hence, the priority ranking for selected suppliers and distributors is obtained by taking into account these evaluations.

Firstly, to calculate the priority rankings of each selected supplier and distributor, we identified the criteria and subcriteria to be used in the analysis. Next, these criteria are structured into a hierarchical form and the group performed pair-wise comparisons among all main criteria and subcriteria. Based on these comparisons of the group, a score is assigned to each subcriterion by using AHP. Scores represent the preferences of the group based on the subcriteria.

Following, the group evaluated the performance levels of selected suppliers and distributors during the audits and assigned a rating to each supplier and distributor. These ratings describe how well a certain supplier or distributor is expected to satisfy the group preferences based on the predetermined criteria and subcriteria. Ratings are the performance values of selected suppliers and distributors on a scale of 0-100 where higher value represents high performance. Henceforth, the rating of each supplier and distributor is determined.

A solution to this multi-criteria decision problem is obtained by using the AHP software, "Expert Choice" (Expert Choice, 1997). For detailed information about the AHP, see section 4.2. Moreover, the issues related to group decision making in the AHP is also discussed in detail in section 4.2.5. The group performed pair-wise comparisons among all criteria and subcriteria by using the Saaty's 1-9 scale in Table 4.1. Next, the AHP matrices are constituted to integrate the scores of all criteria and subcriteria. So the AHP-based analysis results in a specific score for each criterion and subcriterion. Finally, the priorities of selected suppliers and distributors are calculated by multiplying each rating with the score of each subcriteria.

6.3.2.2. Step 2: Transportation Problem

This step identifies the optimal quantities and routing decisions related to supply of raw materials and shipment of finished goods. The transportation model for supply of raw materials takes into consideration the capacities of suppliers, demand of three manufacturers and the priorities of selected suppliers. Likewise, the transportation model for shipment of finished products takes into consideration the capacities of manufacturers, demand of selected distributors and the priorities of selected distributors. For detailed information about transportation model see section 5.4.1.

The design of the transportation network is based on the priorities determined earlier in section 6.3.2.1. Thus, the SCN network for raw materials and finished products is designed by taking into consideration a number of both quantitative and also qualitative criteria.

Assuming that the p suppliers are selected in section 6.3.1.3, the transportation model named as "model 4", expressing the optimal quantity and routing between p suppliers and q manufacturers can be constructed as follows:

$$\min \sum_{i=1}^{p} \sum_{j=1}^{q} (1/t_i)\, x_{ij} \tag{22}$$

s.t.

$$\sum_{j=1}^{q} x_{ij} \leq C_i\ ,\ \forall i, \tag{23}$$

$$\sum_{i=1}^{p} x_{ij} = D_j \, , \forall j, \tag{24}$$

$$x_{ij} \geq 0 \, , \forall i, j, \tag{25}$$

$\mathbf{t_i}$ is the priority of supplier i;
$\mathbf{x_{ij}}$ is the number of units shipped from supplier i to manufacturer j;
$\mathbf{C_i}$ is the capacity of supplier i;
$\mathbf{D_j}$ is the demand of the manufacturer j.

The objective function (22) aims at minimizing the quantity of raw materials to be shipped from selected "p" suppliers to "q" manufacturers.

Constraint (23) states that the sum of the shipments from a supplier cannot exceed the annual production capacity of this supplier.

Constraint (24) states that the sum of the shipments to a manufacturer is equal to the demand of this manufacturer.

The solution of this model results in optimal quantity and routing decisions for supply of raw materials from selected suppliers to three manufacturers.

Likewise, assuming that the r distributors are selected in section 6.3.1.3, the transportation model named as "model 5", expressing the optimal routing between q manufacturers and r distributors can be constructed as follows:

$$\min \sum_{j=1}^{q} \sum_{k=1}^{r} (1/t_k) \, x_{jk} \tag{26}$$

s.t.

$$\sum_{k=1}^{r} x_{jk} \leq C_j \ , \forall j, \qquad (27)$$

$$\sum_{j=1}^{q} x_{jk} = D_k \ , \forall k \neq h, \qquad (28)$$

$$\sum_{j=1}^{q} x_{jh} = (\sum_{j=1}^{q} C_j) - (\sum_{k=1}^{r} D_k), \forall k \neq h, \qquad (29)$$

$$x_{jk,} \ x_{jh} \geq 0 \ , \forall j, k, \qquad (30)$$

where

h is the distributor which has the minimum priority;

$\mathbf{t_k}$ is the priority of distributor k;

$\mathbf{x_{jk}}$ is the number of finished products to be shipped from manufacturer j to distributor k;

$\mathbf{x_{jh}}$ is the number of finished products to be shipped from manufacturer j to distributor h;

$\mathbf{C_j}$ is the capacity of manufacturer j;

$\mathbf{D_k}$ is the demand of the distributor k;

$\mathbf{D_h}$ is the demand of the distributor h.

The objective function (26) aims at minimizing the quantity of finished products to be shipped from “q” manufacturers to selected “r” distributors. It must be noted that using the reciprocals of the priorities specify to supply firstly the demand of the distributor that has the maximum priority.

Constraint (27) states that the sum of the shipments from a manufacturer cannot exceed the annual production capacity of this manufacturer.

Constraint (28) states that the sum of the shipments to a distributor (except the distributor h, that has minimum priority) is equal to the demand of this distributor.

Constraint (29) states that the sum of the shipments to the distributor h, that has minimum priority, is equal to “the total capacity of three manufacturers minus the total demand of distributors with higher priority”. It must be noted that to reflect the company’s desire to minimize the level of inventory, the objective functions in models 4 and 5 are expressed as minimization functions.

6.4. Implementation

6.4.1. Phase 1: Supplier And Distributor Selection

6.4.1.1. Supplier Selection

Since the production of a light commercial vehicle requires a large number of components, the potential suppliers are classified into nine groups according to the material types. All suppliers in each group are assumed to be shipping identical production components. The groups and the number of suppliers in each group are listed as follows:

1. Air Systems (6 suppliers)
2. Auto Tyres (5 suppliers)
3. Chemical Materials (6 suppliers)
4. Electric Materials (17 suppliers)
5. Plastic & Polyester & Glass Materials (18 suppliers)
6. Radiator & Intercooler (5 suppliers)
7. Sawdust Manufacturing & Casting & Forging & Connection Elements & Assembly Parts (50 suppliers)
8. Sheet Iron & Welded Assemblies (30 suppliers)
9. Trim & Rubber Materials (19 suppliers)

To evaluate these nine group of suppliers, two input and four output measures are used. Input measures are:

1. **Total cost (TC):** This measure is defined as the total logistics and procurement cost of the raw materials.

2. **Experience (EX):** This measure is defined as working experience of supplier with the company. Experience is intangible supplier performance factor that represents responsiveness, access, courtesy, communication, and trust.

The output measures are:

1. **Percentage of on-time deliveries (OTD):** This measure is defined as the timely transfer or exchange of the raw materials and the ability to deliver to the manufacturers according to the target schedule.

2. **Acceptance rate (AR):** Some of the lots are rejected in the incoming quality control due to low quality of the material. This measure is defined as the percentage of accepted units in the total units received.

3. **Post transaction service level (SL):** The function of a supplier does not end when goods are provided to the company. Post transaction service level plays an important role and provides valuable feedback that can be used to further improve supplier relationships and supplier performance.

4. **Defect rate (DR):** This measure is defined as the percentage of defective units in the total units received.

Data on these input and output measures are based on the recent audits performed by the company. To reflect the performance of the suppliers, numerical values based on a scale of 0-100 are given. High values indicate good performance. To illustrate the steps involved in supplier selection, only the fourth group, supplying electric materials, has been taken into consideration in this section. Data and the results for other groups can be found in Appendix A1-A4.

6.4.1.1.1. Step 1. Application of CCR Model

This step generates a relative efficiency score for each candidate supplier by taking into consideration the input and output measures given in earlier section. Numerical values based on a scale of 0-100 are given to each candidate supplier for input and output measures to reflect that supplier's performance. These supplier data of electric materials are provided in Table 6.1.

Table 6.1 Supplier data of electric materials

SUPPLIERS	LOCATION	INPUTS		OUTPUTS			
		TC	EX	OTD	AR	SL	DR
1	İSTANBUL	90	75	100	100	89	98
2	ANKARA	80	95	58	100	80	49
3	İSTANBUL	80	90	59	95	79	86
4	İSTANBUL	80	90	94	97	91	72
5	İSTANBUL	80	66	44	95	67	1
6	İSTANBUL	80	90	70	65	71	78
7	SAKARYA	80	90	73	94	83	22
8	BURSA	70	95	24	96	76	1
9	İSTANBUL	80	90	34	84	71	95
10	KIRKLARELİ	80	90	40	96	76	1
11	İZMİR	81	60	54	99	67	90
12	İSTANBUL	90	76	51	95	72	30
13	İSTANBUL	60	95	81	78	79	66
14	BURSA	70	90	83	100	85	5
15	İSTANBUL	60	90	72	98	80	24
16	İSTANBUL	80	75	29	79	64	1
17	İSTANBUL	60	84	41	95	71	40

The relative efficiency scores of 17 suppliers are evaluated by using the DEA software "Efficiency Measurement System" (EMS) (Efficiency Measurement System, 2000). The relative efficiency scores of electric materials are provided in Table 6.2.

Table 6.2 The relative efficiency scores for suppliers of electric materials

SUPPLIERS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1*	%1,325	1,000
2	%0,873	0,873
3	%0,963	0,963
4*	%1,005	1,000
5	%0,943	0,942
6	%0,872	0,872
7	%0,910	0,910
8	%0,881	0,881
9*	%1,069	1,000
10	%0,860	0,859
11*	%1,231	1,000
12	%0,861	0,861
13*	%1,182	1,000
14*	%1,001	1,000
15*	%1,122	1,000
16	%0,792	0,792
17*	%1,049	1,000

Based on the results given in Table 6.2, the suppliers 1, 4, 9, 11, 13, 14, 15 and 17 are identified to be efficient with a relative efficiency score of 1. As mentioned in detail in section 6.3.1.1, the relative efficiency scores obtained from the CCR model may not accurately determine the performance of some suppliers because the input and output weights are unrestricted. To overcome this problem of the CCR model, the cross-evaluations are conducted to discriminate between good and poor performers by utilizing the PEG formulation.

6.4.1.1.2. Step 2. Pair-Wise Efficiency Game Formulation

In this step, the PEG formulation, given as model 1 in section 6.3.1.2, is utilized to evaluate the cross-efficiency scores of the candidate suppliers by taking into consideration both input and output measures and also relative efficiency scores calculated in earlier step.

It must be noted that, in the PEG formulations of the first supplier, the first supplier is the test supplier, which is compared to other 16 suppliers, consecutively. The following model gives the comparison between the first and the second supplier. It must be noted that the second supplier is considered as the target supplier in the below model.

$\min 100u_1+100u_2+89u_3+98u_4$ (31)

s.t.

$90v_1+75v_2=1$ (32)

$58u_1+100u_2+80u_3+49u_4-69.84v_1-82.935v_2=0$ (33)

$100u_1+100u_2+89u_3+98u_4-90v_1-75v_2<=0$ (34)

$u_1, u_2, u_3, u_4, v_1, v_2 >=0$ (35)

The PEG formulation is solved using Lindo. The CCR score and the PEG results for each supplier are used to calculate the M_EFF score of that supplier. The results can be seen in Table 6.3. Diagonal values show the relative efficiency scores obtained by the CCR model for each supplier.

Table 6.3 The results of PEG formulation and M_EFF scores for suppliers of electric materials

Target \ Test	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	**1,000**	0,395	0,492	0,612	0,011	0,542	0,187	0,008	0,283	0,009	0,600	0,302	0,532	0,043	0,204	0,010	0,364
2	0,776	**0,873**	0,829	0,847	0,018	0,567	0,392	0,018	0,512	0,018	0,722	0,475	0,681	0,094	0,451	0,018	0,698
3	0,901	0,520	**0,963**	0,806	0,011	0,659	0,246	0,011	0,555	0,011	0,807	0,299	0,700	0,056	0,269	0,011	0,480
4	0,869	0,585	0,628	**1,000**	0,014	0,670	0,306	0,013	0,362	0,014	0,567	0,370	0,762	0,069	0,333	0,014	0,467
5	0,873	0,689	0,691	0,705	**0,942**	0,473	0,684	0,357	0,534	0,628	0,930	0,818	0,537	0,727	0,713	0,546	0,690
6	0,972	0,519	0,735	0,805	0,011	**0,872**	0,246	0,011	0,424	0,011	0,664	0,298	0,699	0,056	0,268	0,011	0,479
7	0,861	0,685	0,735	0,939	0,041	0,629	**0,910**	0,039	0,424	0,041	0,665	0,565	0,715	0,207	0,877	0,041	0,548
8	0,714	0,803	0,763	0,779	0,680	0,522	0,755	**0,881**	0,675	0,771	0,671	0,649	0,716	0,918	0,949	0,634	0,931
9	0,917	0,489	0,905	0,758	0,011	0,774	0,232	0,010	**1,000**	0,011	0,932	0,281	0,658	0,053	0,253	0,011	0,451
10	0,795	0,848	0,850	0,868	0,757	0,582	0,841	0,488	0,730	**0,859**	0,748	0,723	0,661	0,895	0,877	0,623	0,860
11	0,808	0,344	0,637	0,533	0,010	0,438	0,163	0,007	0,420	0,007	**1,000**	0,263	0,463	0,037	0,178	0,009	0,317
12	0,906	0,725	0,727	0,742	0,032	0,497	0,533	0,023	0,485	0,024	0,890	**0,861**	0,566	0,121	0,582	0,029	0,626
13	0,751	0,537	0,546	0,818	0,011	0,625	0,250	0,013	0,315	0,011	0,494	0,303	**1,000**	0,065	0,364	0,011	0,506
14	0,778	0,611	0,622	0,849	0,175	0,569	0,770	0,189	0,358	0,175	0,562	0,478	0,739	**1,000**	0,867	0,175	0,529
15	0,680	0,604	0,615	0,742	0,031	0,497	0,688	0,036	0,354	0,031	0,556	0,472	0,754	0,179	**1,000**	0,031	0,569
16	0,891	0,782	0,794	0,810	0,792	0,543	0,785	0,517	0,702	0,660	0,819	0,792	0,617	0,835	0,819	**0,792**	0,784
17	0,702	0,789	0,750	0,766	0,019	0,513	0,413	0,021	0,622	0,019	0,019	0,500	0,726	0,107	0,560	0,019	**1,000**
M_EFF SCORES	**0,835**	**0,635**	**0,722**	**0,787**	**0,210**	**0,587**	**0,494**	**0,155**	**0,515**	**0,194**	**0,685**	**0,497**	**0,678**	**0,321**	**0,563**	**0,176**	**0,606**

For instance, when the first supplier is the test supplier, the relative efficiency score is 1 and when it is compared to the second supplier, the PEG result is 0.776. By taking into account the relative efficiency score, 1 and the other 16 PEG results for the first supplier, the average value (M_EFF score) is calculated as 0.835. When the fifth supplier is the test supplier, the relative efficiency score is 0.942 and when it is compared to the second supplier, the PEG result is 0.018. By taking into account the relative efficiency score, 0.942 and the other 16 PEG results for the fifth supplier, the average value (M_EFF score) is calculated as 0.210. M_EFF scores for the other suppliers are determined in the same manner.

It is interesting to note that the supplier 3, which was found to be inefficient as a result of applying the CCR model in earlier step, here it was found to have a better performance (i.e., M_EFF score for supplier 3 is 0.772) than the suppliers 9, 11, 13, 14, 15 and 17, which were identified as efficient in earlier step. This result clearly demonstrates the usefulness of the PEG model in differentiating between good and bad performers.

6.4.1.1.3. Step 3. Selection Of Suppliers

This step employs the integer-programming model, given as model 2 in section 6.3.1.3, to identify the optimal suppliers by taking into consideration the capacities, location ratings and the aggregated mean efficiency scores, M_EFF scores, of candidate suppliers and also the demand of three manufacturers.

Location rating (L_i) represents the closeness of each supplier to the company. Each candidate supplier is provided a location rating on a scale of 0-100. The higher the location rating, the closer supplier to the manufacturing site. The data regarding location ratings (LOC) and the production capacities of 17 candidate suppliers for one year (CAP) are given in Table 6.4.

Table 6.4 Location and capacity data for suppliers of electric materials

SUPPLIERS	LOC	CAP
1	87	641239
2	86	573952
3	87	571631
4	87	656240
5	87	482339
6	87	511219
7	87	595960
8	91	543930
9	87	514159
10	86	547157
11	100	613920
12	87	521662
13	87	571696
14	91	484608
15	87	578192
16	87	458358
17	87	509666

The required lowest M_EFF scores and the required lowest location ratings of supplier groups and also the forecasted demand values of three manufactures for each supplier group are given in Table 6.5. It must be noted that, all data on demand for raw materials are based on the forecasted values, since we concentrated on designing a SCN for a recently introduced product.

Table 6.5 The required lowest M_EFF scores, location ratings and demand values for all supplier groups

No	Supplier Groups	The Required Lowest M_EFF Scores	The Required Lowest Location Ratings	Demand of Manufacturer 1	Demand of Manufacturer 2	Demand of Manufacturer 3	Total Demand
1	Air Systems	0,60	90	44664	71462	17866	133992
2	Auto Tyres	0,74	90	31332	50131	12533	93996
3	Chemical Materials	0,79	98	162852	260563	65141	488556
4	Electrical Materials	0,51	88	632544	1012070	253018	1897632
5	Plastic & Polyester & Glass	0,38	92	759960	1215936	303984	2279880
6	Radiator & Intercooler	0,72	92	7200	11520	2880	21600
7	Sawdust Manufacturing & Casting & Forging & Connection Elements & Assembly Parts	0,45	92	2778180	4445088	1111272	8.334.540
8	Sheet Iron & Welded Assemblies	0,50	92	2129160	3406656	851664	6387480
9	Trim & Rubber Materials	0,54	91	1034136	1654618	413654	3102408

The required lowest M_EFF score and location rating for electric materials are given as 0.51 and 88, which are the average value of M_EFF scores and the average value of location ratings of 17 candidate suppliers, respectively. In summary, 17 suppliers are evaluated by restricting the required lowest M_EFF score to be greater than or equal to 0.51 and the required lowest location rating to be greater than or equal to 88. As a third constraint, total capacity of selected suppliers must be greater than or equal to 1897632 units. It must be noted that unless a supplier's performance on these criteria is better than these critical values, it is not taken into consideration during the evaluation process.

By using these data, the model given as below is constructed to select the optimal suppliers of electric materials:

$$\min X_1+X_2+X_3+X_4+X_5+X_6+X_7+X_8+X_9+X_{10}+X_{11}+X_{12}+X_{13}+X_{14}+X_{15}+X_{16}+X_{17} \quad (36)$$

s.t.

$$0.835X_1+0.635X_2+0.722X_3+0.787X_4+0.21X_5+0.587X_6+0.494X_7+0.155X_8+0.515X_9 +0.194X_{10}+0.685X_{11}+0.497X_{12}+0.678X_{13}+0.321X_{14}+0.563X_{15}+0.176X_{16}+0.606X_{17}- 0.51X_1-0.51X_2-0.51X_3-0.51X_4-0.51X_5-0.51X_6-0.51X_7-0.51X_8-0.51X_9-0.51X_{10}- 0.51X_{11}-0.51X_{12}-0.51X_{13}-0.51X_{14}-0.51X_{15}-0.51X_{16}-0.51X_{17}>=0 \quad (37)$$

$$87X_1+86X_2+87X_3+87X_4+87X_5+87X_6+87X_7+91X_8+87X_9+86X_{10}+100X_{11}+87X_{12}+87 X_{13}+91X_{14}+87X_{15}+87X_{16}+87X_{17}-88X_1-88X_2-88X_3-88X_4-88X_5-88X_6-88X_7-88X_8- 88X_9-88X_{10}-88X_{11}-88X_{12}-88X_{13}-88X_{14}-88X_{15}-88X_{16}-88X_{17}>=0 \quad (38)$$

$$641239X_1+573952X_2+571631X_3+656240X_4+482339X_5+511219X_6+595960X_7+543 930X_8+514159X_9+547157X_{10}+613920X_{11}+521662X_{12}+571696X_{13}+484608X_{14}+578 192X_{15}+458358X_{16}+509666X_{17}>= 1897632 \quad (39)$$

$$\text{INT } X_{i,} \ \forall X_i \quad (40)$$

As mentioned in section 6.3.1.3, $\mathbf{X_i}$ is a binary variable that indicates the selection of each candidate supplier. (i=1,....,17)

Objective function (36) aims at minimizing the number of selected suppliers.

The constraint (37) states that the aggregated mean efficiency scores, M_EFF scores, of the selected suppliers are equal or higher than 0.51.

The constraint (38) states that the location ratings of the selected suppliers are equal or higher than 88.

The constraint (39) states that the total capacity of the selected suppliers is equal or higher than 1897632.

The integer-programming model constructed to select the optimal suppliers is solved using Lindo. As seen in Table 6.6, the suppliers 1, 4 and 11 are selected to take place in the SCN to supply electric materials. These suppliers are not only good performers with respect to their internal operating practices, but also, as a group, satisfy the required lowest M_EFF scores, location and capacity constraints. The decisions taken for the supply of other material groups can be also seen in Table 6.6.

Table 6.6 Results of the selection step for all suppliers of nine groups

No	**Supplier Groups**	**Number of the Selected Suppliers**
1	Air Systems	2,5,6
2	Auto Tyres	3,4,5
3	Chemical Materials	2,4,5
4	Electric Materials	1,4,11
5	Plastic & Polyester & Glass Materials	3,5,7,15
6	Radiator & Intercooler	3,4,5
7	Sawdust Manufacturing & Casting & Forging & Connection Elements & Assembly Parts	4,7,17,20,40,43,48
8	Sheet Iron & Welded Assemblies	1,9,17,22
9	Trim & Rubber Materials	2,6,8,16

6.4.1.2. Distributor Selection

Another problem we dealt with in this paper is to select the distributors for the shipment of finished products. The 64 distributors are placed into 6 groups based on the region:

1. Adana (10 distributors)
2. Ankara (9 distributors)
3. Diyarbakır (7 distributors)
4. İstanbul (10 distributors)
5. İzmir (22 distributors)
6. Samsun (6 distributors)

To evaluate these six groups of distributors, one input and three output measures are used. Input measure is:

1. **Operating costs per dollar revenue (OC):** This measure demonstrates how much it costs to generate a dollar of revenue from a particular distributor. It compares activity expense to per dollar revenue received.

The output measures are:

1. **Percentage of on-time deliveries (OTD):** This measure is defined as the timely transfer or exchange of the finished products to the ultimate customers.

2. **Service level (SL):** This measure is defined as percentage of time without stockouts.

3. **Percentage of accurately handled customer orders (AHO):** This measure is defined as the ability to deliver the finished products that conform to what was prespecified upon entering the contract in terms of the general ability to handle orders and satisfy customers.

Data on these input and output measures are based on the recent audits performed by the company. To reflect the performance of the distributors, numerical values based on a scale of 0-100 are given. High values indicate good performance. To illustrate the steps involved in distributor selection, only the second group, the region of Ankara, has been taken into consideration in this section. Data and the results for other groups can be found in Appendix B1-B4.

6.4.1.2.1. Step 1. Application Of CCR Model

This step generates a relative efficiency score for each candidate distributor using the same methodology employed for supplier selection. Numerical values based on a scale of 0-100 are given to each candidate distributor for input and output measures to reflect that distributor's performance. These distributor data of electric materials are provided in Table 6.7.

Table 6.7 Distributor data of the distributors within the region of Ankara

DISTRIBUTORS	LOCATION	INPUT	OUTPUTS		
		OC	OTD	SL	AHO
1	ANKARA	60	25	90	90
2	ANKARA	80	92	90	95
3	KONYA	80	63	88	85
4	BOLU	80	30	50	75
5	ESKİŞEHİR	80	36	45	26
6	KARABÜK	100	77	71	45
7	ANKARA	90	68	95	97
8	YOZGAT	90	78	79	88
9	ZONGULDAK/EREĞLİ	80	66	75	87

Likewise, the relative efficiency scores of 9 distributors are evaluated by using the DEA software "Efficiency Measurement System" (EMS) (Efficiency Measurement System, 2000). The relative efficiency scores of electric materials are provided in Table 6.8.

Table 6.8 The relative efficiency scores for the distributors within the region of Ankara

DISTRIBUTORS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1*	%133,33	1,000
2*	%132,69	1,000
3	%87,72	0,877
4	%65,41	0,654
5	%46,27	0,462
6	%66,96	0,669
7	%84,17	0,841
8	%80,30	0,803
9	%85,78	0,857

Based on the results given in Table 6.8, the distributors 1 and 2 are identified to be efficient with a relative efficiency score of 1. As mentioned in detail in section 6.3.1.1, the relative efficiency scores obtained from the CCR model may not accurately determine the performance of some distributors because the input and output weights are unrestricted. To overcome this problem of the CCR model, the cross-evaluations are conducted to discriminate between good and poor performers by utilizing the PEG formulation.

6.4.1.2.2. Step 2. Pair-Wise Efficiency Game Formulation

In this step, the PEG formulation, given as model 1 in section 6.3.1.2, is utilized to evaluate the cross-efficiency scores of the candidate distributors by taking into consideration both input and output measures and also relative efficiency scores calculated in earlier step.

It must be noted that, in the PEG formulations of the first distributor, the first distributor is the test distributor, which is compared to other 8 distributors, consecutively. The following model gives the comparison between the first and the second distributor. It must be noted that the second distributor is considered as the target distributor in the below model.

$\min 25u_1+90u_2+90u_3$ (41)

s.t.

$60v_1=1$ (42)

$92u_1+90u_2+95u_3-80v_1=0$ (43)

$25u_1+90u_2+90u_3-60v_1<=0$ (44)

$u_1, u_2, u_3, v_1 >= 0$ (45)

The PEG formulation is solved using Lindo. The CCR score and the PEG results for each distributor are used to calculate the M_EFF score of that distributor. The results can be seen in Table 6.9. Diagonal values show the relative efficiency scores obtained by the CCR model for each distributor.

Table 6.9 The results of PEG formulation and M_EFF scores for the distributors within the region of Ankara

Test / Target	1	2	3	4	5	6	7	8	9
1	**1,000**	0,750	0,708	0,417	0,217	0,300	0,704	0,585	0,625
2	0,362	**1,000**	0,685	0,326	0,274	0,379	0,657	0,754	0,717
3	0,464	0,897	**0,877**	0,418	0,268	0,371	0,841	0,700	0,747
4	0,727	0,828	0,741	**0,654**	0,227	0,314	0,752	0,682	0,759
5	0,428	0,924	0,809	0,385	**0,462**	0,583	0,776	0,721	0,770
6	0,362	0,999	0,684	0,326	0,391	**0,669**	0,656	0,753	0,717
7	0,464	0,896	0,829	0,417	0,254	0,351	**0,841**	0,699	0,747
8	0,386	0,975	0,730	0,347	0,267	0,370	0,700	**0,803**	0,764
9	0,433	0,936	0,818	0,390	0,256	0,355	0,785	0,771	**0,857**
M_EFF SCORES	**0,514**	**0,912**	**0,765**	**0,409**	**0,291**	**0,410**	**0,746**	**0,719**	**0,745**

For instance, when the first distributor is the test distributor, the relative efficiency score is 1 and when it is compared to the second distributor, the PEG result is 0.362. By taking into account the relative efficiency score, 1, and the other 8 PEG results for the first distributor, the average value (M_EFF score) is calculated as 0.514. When the fifth distributor is the test distributor, the relative efficiency score is 0.462 and when it is compared to the second distributor, the PEG result is 0.274. By taking into account the relative efficiency score, 0.462 and the other 8 PEG results for the fifth distributor, the average value (M_EFF score) is calculated as 0.291. M_EFF scores for the other distributors are determined in the same manner.

It is interesting to note that the distributor 3, which was found to be inefficient as a result of applying the CCR model in earlier step, here it was found to have a better performance than the distributor 1, which was indicated as efficient in earlier step. This result clearly demonstrates the usefulness of the PEG model, in differentiating between good and bad performers.

6.4.1.2.3. Step 3. Selection Of Distributors

This step employs the integer-programming model, given as model 3 in section 6.3.1.3, to identify the optimal distributors by taking into consideration the demand values, location ratings and the aggregated mean efficiency scores, M_EFF scores, of candidate distributors and also the capacities of three manufacturers.

Location rating (L_i) represents the closeness of each distributor to the company. Each candidate distributor is provided a location rating on a scale of 0-100. The higher the location rating, the closer distributor to the manufacturing site. The data regarding location ratings (LOC) and the demand values of 9 candidate distributors for one year (DEM) are given in Table 6.10.

Table 6.10 Location and demand data for the distributors within the region of Ankara

DISTRIBUTORS	LOC	DEM
1	86	1878
2	86	1495
3	86	1355
4	86	1322
5	89	688
6	82	1237
7	86	1892
8	80	1828
9	62	1697

The required lowest M_EFF scores and the required lowest location ratings of distributor groups and also the allocated capacities of three manufactures to each distributor group are given in Table 6.11. It must be noted that, all data on demand for finished products are based on the forecasted values, since we concentrated on designing a SCN for a recently introduced product.

Table 6.11 The required lowest M_EFF scores and location ratings for all distributor groups and allocated capacities of three manufacturers to each distributor group

No	Distributor Groups	The Required Lowest M_EFF	The Required Lowest Location Ratings	Capacity of First Manufacturer	Capacity of Second Manufacturer	Capacity of Third Manufacturer	Total Capacity
1	Adana	0,63	77	876	1402	350	2628
2	Ankara	0,61	83	872	1395	349	2616
3	Diyarbakır	0,77	66	296	474	118	888
4	İstanbul	0,69	88	2164	3462	866	6492
5	İzmir	0,50	94	1276	2042	510	3828
6	Samsun	0,81	72	456	730	182	1368

The required lowest M_EFF score and location rating for the distributors within the region of Ankara are given as 0.61 and 83, which are the average value of M_EFF scores and the average value of location ratings of 9 candidate distributors, respectively. In summary, 9 distributors are evaluated by restricting the required lowest M_EFF score to be greater than or equal to 0.61 and the required lowest location rating to be greater than or equal to 83. Moreover, the choice of distributors will be limited by the total allocated capacity of the manufacturers to the region of Ankara (2616 units). It must be noted that unless a distributor's performance on these criteria is better than these critical values, it is not taken into consideration during the evaluation process.

By using these data, the model given as below is constructed to select the optimal distributors within the region of Ankara:

$$\min X_1+X_2+X_3+X_4+X_5+X_6+X_7+X_8+X_9 \quad (46)$$

s.t.

$$0.514X_1+0.912X_2+0.765X_3+0.409X_4+0.291X_5+0.41X_6+0.746X_7+0.719X_8+0.745X_9-0.61X_1-0.61X_2-0.61X_3-0.61X_4-0.61X_5-0.61X_6-0.61X_7-0.61X_8-0.61X_9>=0 \quad (47)$$

$$86X_1+86X_2+86X_3+86X_4+89X_5+82X_6+86X_7+80X_8+62X_9-83X_1-83X_2-83X_3-83X_4-83X_5-83X_6-83X_7-83X_8-83X_9>=0 \quad (48)$$

$$1878X_1+1495X_2+1355X_3+1322X_4+688X_5+1237X_6+1892X_7+1828X_8+1697X_9 >= 2616 \quad (49)$$

$$\text{INT } X_i, \forall X_i \quad (50)$$

As mentioned in section 6.3.1.3, $\mathbf{X_i}$ is a binary variable that indicates the selection of each candidate distributor. (i=1,....,9)

Objective function (46) aims at minimizing the number of selected distributors.

The constraint (47) states that the aggregated mean efficiency scores, M_EFF scores, of the selected distributors are equal or higher than 0.61.

The constraint (48) states that the location ratings of the selected distributor are equal or higher than 83.

The constraint (49) states that the total demand of the selected distributors is equal or higher than 2616.

The integer-programming model constructed to select the optimal distributors is solved using Lindo. As seen in Table 6.12, the distributors 2 and 3 are selected to take place in the SCN for the region of Ankara. Table 6.12 also lists the decisions taken for the remaining distributor groups.

Table 6.12 Results of the selection step for all distributors of six groups

DISTRIBUTOR NUMBER	Distributor Groups	Number of the Selected Distributors
1	Adana	8,10
2	Ankara	2,3
3	Diyarbakır	1,2
4	İstanbul	2,4
5	İzmir	8,13
6	Samsun	2,6

6.4.2.Phase 2: Transportation From Suppliers To Manufacturers And From Manufacturers To Distributors

This phase identifies the optimal quantity and routing decisions for supply of raw materials and shipment of finished products. It must be noted that transportation models constructed for these decisions take into consideration the group preferences on performance of selected suppliers and distributors. Thus, the SCN can be designed by taking into consideration a number of both quantitative and qualitative criteria.

6.4.2.1. Transportation From Selected Suppliers To Manufacturers

This section presents the procedure employed to identify the optimal quantity and routing of raw materials to be shipped from selected suppliers to three manufacturers.

6.4.2.1.1. Step 1: Determination Of The Priority Ranking Using AHP

The priorities of selected suppliers are determined by taking into consideration the group preferences on performance of these suppliers. As mentioned earlier, the group consists of 10 members of the company, whose decisions are effective on management of the company.

Priorities for suppliers specify to procure the raw materials firstly from the supplier that has the maximum priority.

Firstly, we identified four main criteria to be included in the analysis: reliability, flexibility, discipline and cost. In order to reach an adequate level of detail in the analysis, reliability, flexibility and discipline are further divided into two subelements.

Reliability: Reliability consists of the following subcriteria: the ability to deliver products to the manufacturers according to the target schedule as discussed in section 6.4.1.1 (On Time Delivery) and requested quality (Quality).

Flexibility: Flexibility refers to the ability of a supplier to respond to changes in the demand of the manufacturers (Capacity Adjustments) and conform to any special requests set by the manufacturers (Special Requests).

Discipline: Discipline consists of the following subcriteria: the working experience of supplier with the company as discussed in section 6.4.1.1 (Experience) and the ability to obey the procedures of the company (Procedural Compliance).

Cost: The fourth main criterion, cost, refers to the total logistics cost and procurement cost of raw materials for the company as discussed in section 6.4.1.1.

The criteria included in the analysis are structured into the form of a hierarchy as shown in Figure 6.1. The overall goal for the analysis is located at the highest level of the hierarchy, the main criteria can be found at the second level, and the subcriteria can be found at the third level. The goal is to analyse selected suppliers and the main criteria are reliability, flexibility, discipline and cost. The subcriteria are on time delivery, quality, capacity adjustments, special requests, experience, and procedural compliance.

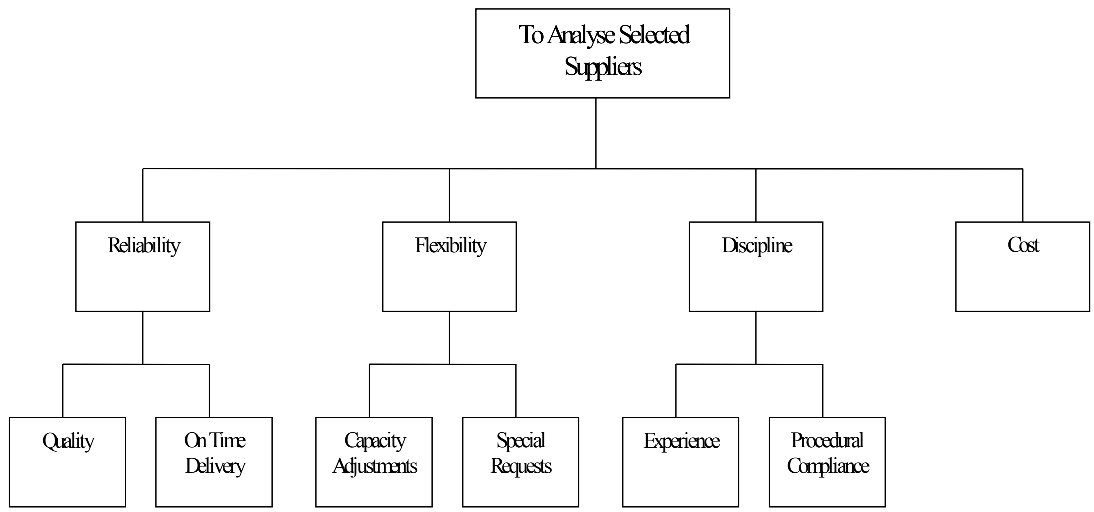


Figure 6.1 The hierarchy for analysing the selected suppliers

Correspondingly, the group evaluated the performance levels of selected suppliers based on the above subcriteria during the audits. The results of this evaluation for each selected supplier are called as ratings. As mentioned earlier, ratings describe how well a certain supplier is expected to satisfy the group preferences based on the predetermined criteria and subcriteria. To reflect the performance of the selected suppliers, numerical values based on a scale of 0-100 are given where high values indicate good performance. The ratings for each selected supplier of electric materials are given in Table 6.13.

Table 6.13 Ratings for each selected supplier of electric materials

Subcriteria / Suppliers	Quality	On Time Delivery	Capacity Adjustments	Special Requests	Experience	Procedural Compliance	Cost
1	95	100	82	95	75	94	90
4	81	94	84	92	90	69	80
11	91	54	62	94	60	86	81

Following, the AHP is used to analyze the scores of subcriteria by taking into the consideration the group preferences. As mentioned before, the scores represent the preferences of the group based on supplier selection subcriteria. For detailed information about the AHP, see section 4.2.

"Expert Choice" (Expert Choice, 1997) is utilized to solve the AHP problem. Tree view of the hierarchy in Expert Choice that is used for the weight calculation in the problem, is shown as Figure 6.2.

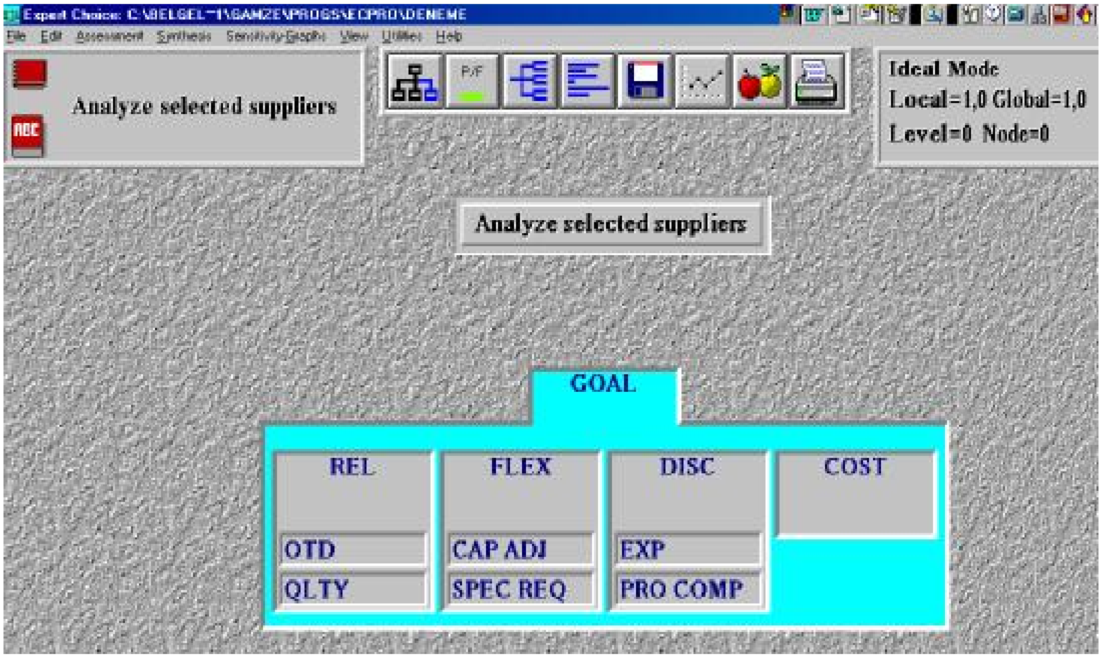
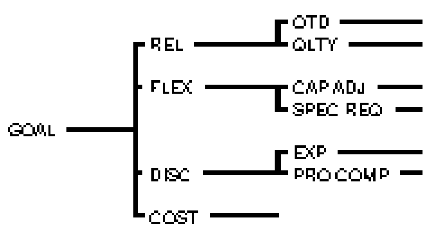


Figure 6.2 Tree view of the hierarchy in Expert Choice

Sideway view and abbreviations used in Expert Choice is also shown as Figure 6.3.



Abbreviation	Definition
GOAL	
CAP ADJ	Capacity Adjustments
COST	Cost
DISC	Discipline
EXP	Experience
FLEX	Flexibility
OTD	On Time Delivery
PRO COMP	Procedural Compliance
QLTY	Quality
REL	Reliability
SPEC REQ	Special Requests

Figure 6.3 Sideway view and abbreviations used in Expert Choice

The group performed comparative judgments among all criteria and subcriteria by using the Saaty's 1-9 scale in Table 4.1. The comparisons of each member of the group for each criterion can be seen in Table 6.14.

Table 6.14 Comparisons of the group for criteria

Members Of Group	**GOAL**					
	Reliability-Flexibility	Reliability-Discipline	Reliability-Cost	Flexibility-Discipline	Cost-Flexibility	Discipline-Cost
1	5	7	3	3	3	0,20
2	4	8	3	4	3	0,17
3	6	7	3	3	3	0,20
4	5	6	3	2	3	0,25
5	5	8	3	3	3	0,20
6	5	6	3	3	3	0,20
7	6	7	3	3	3	0,20
8	5	7	3	3	3	0,20
9	5	6	3	2	3	0,25
10	4	8	3	4	3	0,17
AVG	5	7	3	3	3	0,20

In the same manner, each member compared two of each subcriterion. The comparisons of the group for the subcriteria of reliability, flexibility and discipline can be seen in Table 6.15, Table 6.16 and Table 6.17, respectively.

Table 6.15 Comparisons for "Reliability"

Members Of Group	**RELIABILITY**
	Quality- On Time Delivery
1	4
2	5
3	5
4	3
5	4
6	4
7	3
8	3
9	4
10	5
AVG	4

Table 6.16 Comparisons for "Flexibility"

Members Of Group	**FLEXIBILITY**
	Capacity Adjustments-Special Requests
1	3
2	3
3	3
4	2
5	2
6	4
7	3
8	2
9	4
10	4
AVG	**3**

Table 6.17 Comparisons for "Discipline"

Members Of Group	DISCIPLINE Experience-Procedural Compliance
1	7
2	9
3	6
4	7
5	8
6	7
7	5
8	6
9	9
10	6
AVG	**7**

Finally, the AHP matrices are constituted to integrate the scores for all main criteria. AHP matrice and the scores obtained by Expert Choice for the criteria can be seen in Figure 6.4.

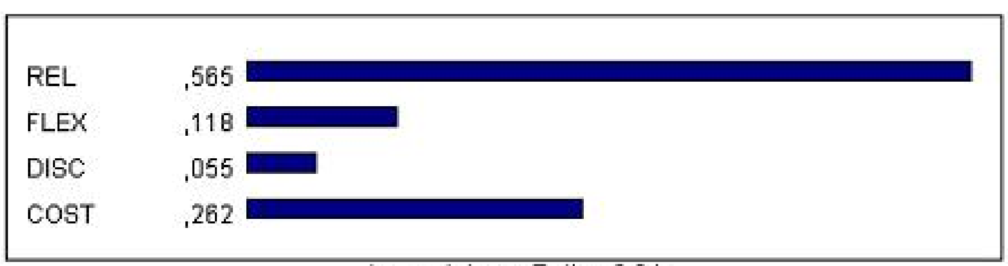
Analyze selected suppliers

Node: 0

Compare the relative IMPORTANCE with respect to: GOAL <

	FLEX	DISC	COST
REL	5,0	7,0	3,0
FLEX		3,0	(3,0)
DISC			(5,0)

Abbreviation	Definition
Goal	Analyze selected suppliers
REL	Reliability
FLEX	Flexibility
DISC	Discipline
COST	Cost



Inconsistency Ratio =0,04

Figure 6.4 AHP matrice and the scores for criteria

The scores for reliability, flexibility, discipline and cost are found to be 0.565, 0.118, 0.055 and 0.262, respectively. Inconsistency ratio is calculated as 0.04, which is smaller than 0.10 so it can be said that this comparison is consistent. Detailed information about consistency ratio is introduced in section 4.2.6. In the same manner, the AHP matrices for the subcriteria of reliability, flexibility and discipline are constituted as in Table 6.18, Table 6.19 and Table 6.20, respectively.

Table 6.18 AHP matrice for subcriteria of "Reliability"

RELIABILITY	Quality	On Time Delivery
Quality	1	4
On Time Delivery	0,25	1

Table 6.19 AHP matrice for subcriteria of "Flexibility"

FLEXIBILITY	Capacity Adjustments	Special Requests
Capacity Adjustments	1	3
Special Requests	0,33	1

Table 6.20 AHP matrice for subcriteria of "Discipline"

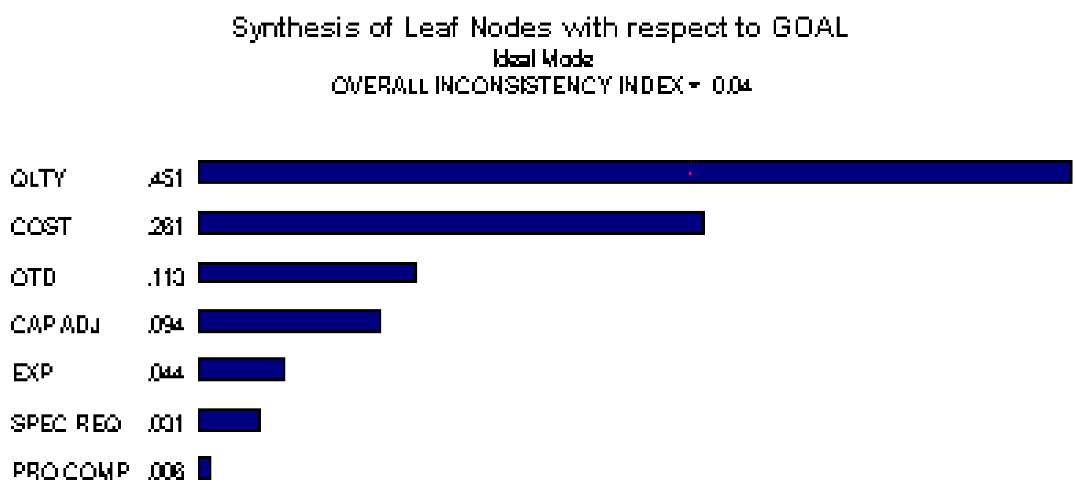
DISCIPLINE	Experience	Procedural Compliance
Experience	1	7
Procedural Compliance	0,14	1

Results of each AHP matrice for the subcriteria calculated by Expert Choice are given in Table 6.21.

Table 6. 21 Results of each AHP matrice for the subcriteria

RELIABILITY	
Quality	0,800
On Time Delivery	0,200
FLEXIBILITY	
Capacity Adjustments	0,750
Special Requests	0,250
DISCIPLINE	
Experience	0,875
Procedural Compliance	0,125

Overall synthesis of all subcriteria by Expert Choice results in the scores of each subcriterion. Abbreviations used in Expert Choice and the scores for subcriteria are shown in Figure 6.5.



Abbreviation	Definition
QLTY	Quality
COST	Cost
OTD	On Time Delivery
CAP ADJ	Capacity Adjustments
EXP	Experience
SPEC REQ	Special Requests
PRO COMP	Procedural Compliance

Figure 6.5 Abbreviations used in Expert Choice and the scores for subcriteria

These scores and the given ratings in Table 6.13 are used to obtain the priorities for the suppliers. Priorities are calculated by multiplying each rating with the score of each subcriteria. (see Table 6.22).

Table 6.22 Analysis for the selected suppliers of electric materials

Electric Materials									
Subcriteria	Quality	On Time Delivery	Capacity Adjustments	Special Requests	Experience	Procedural Compliance	Cost	Total	Priority
Score / Suppliers	0,451	0,113	0,094	0,031	0,044	0,006	0,261	1,000	
1	95	100	82	95	75	94	90	92	0,3608
4	81	94	84	92	90	69	80	83	0,3255
11	91	54	62	94	60	86	81	80	0,3137

The priority represents the overall preference of a certain supplier to the manufacturer. As illustrated in Table 6.22, the supplier 1 has the highest priority, 0.3609, followed by the supplier 4 and 11. The ratings and priorities of the remaining eight groups of raw materials can be seen in Table 6.23.

Table 6.23 Ratings and priorities of other selected suppliers of all nine groups

Subcriteria	Quality	On Time Delivery	Capacity Adjustments	Special Requests	Experience	Procedural Compliance	Cost	Total	Priority
Score / Group	0,451	0,113	0,094	0,031	0,044	0,006	0,261	1,000	
Air Systems									
2	95	94	74	95	61	93	70	85	0,3617
5	74	58	72	86	95	62	75	73	0,3106
6	77	87	76	81	90	72	70	77	0,3277
Auto Tyres									
3	87	100	85	89	90	84	60	81	0,3600
4	74	85	72	76	86	71	40	67	0,2978
5	79	80	76	81	95	76	70	77	0,3422
Chemical Materials									
2	96	87	85	95	95	96	60	84	0,3294
4	95	71	80	95	90	93	70	84	0,3294
5	94	79	81	94	89	92	80	87	0,3412
Plastic & Polyester & Glass Materials									
3	94	60	72	93	90	93	80	84	0,2684
5	85	54	57	94	45	76	90	79	0,2524
7	84	81	65	76	66	92	50	72	0,2300
15	90	66	74	95	90	84	60	78	0,2492
Radiator & Intercooler									
3	90	80	75	93	81	86	60	79	0,3147
4	92	64	73	95	75	88	90	86	0,3426
5	94	97	80	95	75	91	70	86	0,3426
Sawdust Manufacturing & Casting & Forging & Connection Elements & Assembly Parts									
4	95	49	72	95	90	94	70	81	0,1434
7	96	80	76	95	90	96	40	77	0,1363
17	88	91	75	86	76	89	80	84	0,1487
20	95	93	83	93	90	96	70	87	0,1540
40	90	72	76	95	95	84	60	79	0,1398
43	92	69	72	88	83	95	65	80	0,1416
48	80	93	81	95	90	64	60	77	0,1363
Sheet Iron & Welded Assemblies									
1	92	92	80	95	90	87	80	88	0,2500
9	91	98	71	93	47	87	90	88	0,2500
17	93	87	80	92	81	93	90	90	0,2557
22	84	92	80	95	77	73	90	86	0,2443
Trim & Rubber Materials									
2	90	83	78	95	90	84	80	86	0,2493
6	95	86	78	94	88	94	60	83	0,2406
8	94	90	82	95	90	92	80	89	0,2580
16	91	87	81	95	90	85	80	87	0,2522

6.4.2.1.2. Step 2. Transportation Problem

The selection of the transportation network for raw materials is based on the priorities calculated in earlier section. These priorities make it possible to take into account the group member's preferences on selected suppliers. To identify the optimal quantity and routing decisions for supply of raw materials, we integrated these priorities to the transportation model given in section 6.3.2.2.

For the supply of raw materials for electric materials, the related transportation model is given as below:

$$\min \quad 2.772X_{11}+2.772X_{12}+2.772X_{13}+3.072X_{21}+3.072X_{22}+3.072X_{23}+3.188X_{31}+3.188X_{32}+3.188X_{33} \qquad (51)$$

s.t.

$$X_{11}+X_{12}+X_{13}<=641239 \qquad (52)$$
$$X_{21}+X_{22}+X_{23}<=656240 \qquad (53)$$
$$X_{31}+X_{32}+X_{33}<=613920 \qquad (54)$$

$$X_{11}+X_{21}+X_{31}=632544 \qquad (55)$$
$$X_{12}+X_{22}+X_{32}=1012070 \qquad (56)$$
$$X_{13}+X_{23}+X_{33}=253018 \qquad (57)$$

$$X_{11}, X_{12}, X_{13}, X_{21}, X_{22}, X_{23}, X_{31}, X_{32}, X_{33}>=0 \qquad (58)$$

The objective function, (51), aims at minimizing the number of raw materials to be shipped from selected suppliers to three manufacturers by taking into account the reciprocals of the priorities. That specifies to use firstly the supplier that has a maximum priority.

The constraint (52) states that the total number of raw materials to be shipped from the first selected supplier (supplier 1) to three manufacturers is at most 641239.

The constraint (53) states that the total number of raw materials to be shipped from the second selected supplier (supplier 4) to three manufacturers is at most 656240.

The constraint (54) states that the total number of raw materials to be shipped from the third selected supplier (supplier 11) to three manufacturers is at most 613920.

The constraint (55) states that the total number of raw materials to be shipped from all selected suppliers to the first manufacturer is equal to 632544.

The constraint (56) states that the total number of raw materials to be shipped from all selected suppliers to the second manufacturer is equal to 1012070.

The constraint (57) states that the total number of raw materials to be shipped from all selected suppliers to the third manufacturer is equal to 253018.

The above model is solved using Lindo. The optimal number of electric material raw materials to be shipped from each source to each destination is clearly depicted in Table 6.24.

Table 6.24 The solution of the transportation model for the supply of electric materials

Electric Materials				
To / From	**Manufacturer 1**	**Manufacturer 2**	**Manufacturer 3**	**The Reciprocal of Priority**
Supplier 1	632544	-	8695	2,772
Supplier 4	-	656240	-	3,072
Supplier 11	-	355830	244323	3,188

The solutions of the transportation model for other material groups can be seen in Table 6.25.

Table 6.25 The solutions of the transportation model for other material groups

To / From	Manufacturer 1	Manufacturer 2	Manufacturer 3	The Reciprocal of Priority
Air Systems				
Supplier 2	44664	2208	-	2,765
Supplier 5	-	33489	-	3,219
Supplier 6	-	35765	17866	3,052
Auto Tyres				
Supplier 3	12630	14499	12533	2,778
Supplier 4	18702	-	-	3,358
Supplier 5	-	35632	-	2,922
Chemical Materials				
Supplier 2	162852	-	-	3,036
Supplier 4	-	89969	-	3,036
Supplier 5	-	170594	65141	2,931
Plastic & Polyester & Glass Materials				
Supplier 3	348916	410924	-	3,726
Supplier 5	-	695856	-	3,962
Supplier 7	-	109156	-	4,347
Supplier 15	411044	-	303984	4,013
Radiator & Intercooler				
Supplier 3	-	-	2609	3,177
Supplier 4	7200	2935	-	2,919
Supplier 5	-	8585	271	2,919
Sawdust Manufacturing&Casting&Forging&Connection Elements&Assembly Parts				
Supplier 4	1301388	-	-	6,975
Supplier 7	-	233532	1111272	7,338
Supplier 17	-	1207491	-	6,726
Supplier 20	-	1330646	-	6,494
Supplier 40	808019	407635	-	7,152
Supplier 43	-	1265784	-	7,063
Supplier 48	668773	-	-	7,338
Sheet Iron & Welded Assemblies				
Supplier 1	-	895026	851664	4
Supplier 9	1774032	-	-	4
Supplier 17	-	1733845	-	3,911
Supplier 22	355128	777785	-	4,093
Trim & Rubber Materials				
Supplier 2	-	432495	413654	4,012
Supplier 6	494456	-	-	4,157
Supplier 8	-	888423	-	3,876
Supplier 16	539680	333700	-	3,966

6.4.2.2. Transportation From Manufacturers To Selected Distributors

This section presents the results of the procedure employed to identify the decisions for optimal quantity and routing of finished products to be shipped from three manufacturers to selected distributors using the same methodology employed for the supply of raw materials.

6.4.2.2.1. Step 1: Determination Of The Priority Ranking Using AHP

Priorities for distributors specify to supply firstly the demand of the distributor that has the maximum priority. Priorities make it possible to take into account the preferences of the group on selected distributors. It must be noted that to determine the priority ranking of selected distributors, the same set of criteria used for suppliers (see Figure 1) are taken into consideration.

Table 6.26 presents the scores for each subcriterion, the ratings of each selected distributor according to these subcriteria and finally the priorities of selected distributors. In this section, scores represent the preferences of the group based on distributor selection subcriteria. The ratings of selected distributors describe how well a certain distributor is expected to satisfy the group preferences based on the predetermined criteria and subcriteria. To reflect the performance of the selected distributors, numerical values based on a scale of 0-100 are given where high values indicate good performance.

Table 6.26 Analysis for the selected distributors within the region of Ankara

Ankara									
Subcriteria	**Quality**	**On Time Delivery**	**Capacity Adjustments**	**Special Requests**	**Experience**	**Procedural Compliance**	**Cost**	**Total**	**Priority**
Score / Suppliers	0,451	0,113	0,094	0,031	0,044	0,006	0,261	1,000	
2	89	92	89	86	89	95	80	87	0,5210
3	83	63	80	84	79	92	80	80	0,4790

The priority represents the overall preference of a certain distributor to the manufacturer. As illustrated in Table 6.26, distributor 2 has the highest priority, 0.5210, followed by the distributor 3. The ratings and priorities of the remaining five groups of distributors can be seen in Table 6.27.

Table 6.27 Ratings and priorities of other selected distributors of all five groups

Subcriteria	Quality	On Time Delivery	Capacity Adjustments	Special Requests	Experience	Procedural Compliance	Cost	Total	Priority
Groups \ Score	0,451	0,113	0,094	0,031	0,044	0,006	0,261	1,000	
Adana									
8	93	83	92	91	85	100	65	84	0,5217
10	81	72	84	77	78	84	70	77	0,4783
Diyarbakır									
1	84	69	79	86	81	95	80	81	0,4969
2	82	85	84	78	84	85	80	82	0,5031
İstanbul									
2	89	62	89	86	77	95	60	78	0,5065
4	82	80	85	78	78	85	60	76	0,4935
İzmir									
8	93	58	92	91	76	100	51	77	0,4968
13	89	87	89	86	81	95	50	78	0,5032
Samsun									
2	82	84	85	77	81	84	70	79	0,4877
6	89	79	89	87	84	96	70	83	0,5123

6.4.2.2.2. Step 2: Transportation Problem

The selection of the transportation network for the shipment of finished products is based on this priority ranking. To identify the optimal quantity and routing decisions for distribution of finished products, we integrated these priorities to the transportation model given as model 5 in section 6.3.2.2.

For the shipment of finished products within the region of Ankara, the related transportation model is given as below:

$$\min\ 1.92X_{11}+2.088X_{12}+1.92X_{21}+2.088X_{22}+1.92X_{31}+2.088X_{32} \qquad (59)$$

s.t.

$$X_{11}+X_{12}<=872 \qquad (60)$$

$$X_{21}+X_{22}<=1395 \tag{61}$$

$$X_{31}+X_{32}<=349 \tag{62}$$

$$X_{11}+X_{21}+X_{31}=1495 \tag{63}$$

$$X_{12}+X_{22}+X_{32}=1121 \tag{64}$$

$$X_{11}, X_{12}, X_{21}, X_{22}, X_{31}, X_{32} >=0 \tag{65}$$

The objective function, (59), aims at minimizing the number of finished products to be shipped from three manufacturers to selected distributors by taking into account the reciprocals of the priorities. That specifies to supply firstly the demand of the distributor that has a maximum priority.

The constraint (60) states that the total number of finished products to be shipped from the first manufacturer to all selected distributors are at most 872.

The constraint (61) states that the total number of finished products to be shipped from the second manufacturer to all selected distributors are at most 1395.

The constraint (62) states that the total number of finished products to be shipped from the third manufacturer to all selected distributors are at most 349.

The constraint (63) states that the total number of finished products to be shipped from three manufacturers to the first selected distributor (distributor 2) are equal to 1495.

The constraint (64) states that the total number of finished products to be shipped from three manufacturers to the second selected distributor (distributor 3) are equal to 1121.

The above model is solved using Lindo. The optimal number of finished products to be shipped from each source to each destination is clearly depicted in Table 6.28.

Table 6.28 The solution of the transportation model for the selected distributors within the region of Ankara

Ankara		
To / From	**Distributor 2**	**Distributor 3**
Manufacturer 1	100	772
Manufacturer 2	1395	-
Manufacturer 3	-	349
The Reciprocal of Priority	1,920	2,088

The solutions of the transportation model for other regional distributors can be seen in Table 6.29.

Table 6.29 The solutions of the transportation model for other regional distributors

Adana		
From \ To	**Distributor 8**	**Distributor 10**
Manufacturer 1	304	572
Manufacturer 2	1402	-
Manufacturer 3	-	350
The Reciprocal of Priority	1,917	2,091

Diyarbakır		
From \ To	**Distributor 1**	**Distributor 2**
Manufacturer 1	-	296
Manufacturer 2	229	245
Manufacturer 3	-	118
The Reciprocal of Priority	2,012	1,988

İstanbul		
From \ To	**Distributor 2**	**Distributor 4**
Manufacturer 1	1854	310
Manufacturer 2	3462	-
Manufacturer 3	-	866
The Reciprocal of Priority	1,974	2,026

İzmir		
From \ To	**Distributor 8**	**Distributor 13**
Manufacturer 1	-	1276
Manufacturer 2	408	1634
Manufacturer 3	-	510
The Reciprocal of Priority	2,013	1,987

Samsun		
From \ To	**Distributor 2**	**Distributor 6**
Manufacturer 1	-	456
Manufacturer 2	265	465
Manufacturer 3	-	182
The Reciprocal of Priority	2,051	1,952

Finally, as a result of solving transportation models for suppliers and distributors, optimal quantity and routing decisions for raw materials and finished products are made.

CHAPTER SEVEN
CONCLUSION

The main interest of this thesis was to design an efficient SCN for a recently introduced product of an automotive company, light commercial vehicle, by employing a two-phase mathematical programming approach. The expected benefits from the suggested SCN include meeting the constantly changing needs of the customer at low cost, high quality and in short lead times.

The first phase employs a number of multi-criteria efficiency models, CCR and PEG to evaluate the performance of candidate suppliers and distributors. Following, an integer-programming model is solved to select optimal suppliers and distributors under the given efficiency, capacity, demand and location constraints.

In the second phase, two transportation problems are solved in order to identify optimal quantities and routing decisions for supply of raw materials and shipment of finished products. The preferences of the company on the selected suppliers and distributors are determined by using the AHP and these preferences are reflected in transportation models. This approach provides a systematic and flexible framework for determining the priority of each node within the network by taking into account the preferences of the company. Compared to the traditional transportation models, mainly cost oriented approach, the utilization of the AHP enables the inclusion of both quantitative and qualitative factors in the decision process.

As a future work, a decision support system, which automates the steps of the suggested procedure for designing a SCN can be developed. Such a system not only can be used to shorten the time required to design a SCN for new products but also can be employed for existing products to test the efficacy of supply chain decision making at the strategic, tactical and operational levels.

Especially, since the analyses in phase 2 are expected to be carried out more frequently due to changes in demand and capacity constraints, employing a decision support system to deal with the operational issues will certainly help to obtain solutions in much shorter time.

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APPENDIX A1

DATA ON INPUT AND OUTPUT MEASURES FOR THE CANDIDATE SUPPLIERS

Table A1.1 Inputs and outputs data for the candidate suppliers of "Air Systems"

SUPPLIERS	LOCATION	INPUTS		OUTPUTS			
		TC	EX	OTD	AR	SL	DR
1	KOCAELİ	70	95	67	97	84	25
2	KONYA	70	61	94	100	80	97
3	BURSA	80	60	13	68	52	21
4	TEKİRDAĞ	90	90	34	83	72	35
5	İZMİR	75	95	58	90	78	65
6	İSTANBUL	70	90	87	85	83	75

Table A1.2 Inputs and outputs data for the candidate suppliers of "Auto Tyres"

SUPPLIERS	LOCATION	INPUTS		OUTPUTS			
		TC	EX	OTD	AR	SL	DR
1	KOCAELİ	60	90	48	77	75	73
2	KOCAELİ	60	95	39	76	75	72
3	İSTANBUL	60	90	100	94	92	87
4	İZMİR	40	86	85	80	78	74
5	İSTANBUL	70	95	80	85	83	79

Table A1.3 Inputs and outputs data for the candidate suppliers of "Chemical Materials"

SUPPLIERS	LOCATION	INPUTS		OUTPUTS			
		TC	EX	OTD	AR	SL	DR
1	İZMİR	80	90	53	96	80	94
2	MANİSA	60	95	87	100	89	100
3	İSTANBUL	60	81	62	96	80	91
4	İZMİR	70	90	71	100	84	97
5	İZMİR	80	89	79	99	85	96
6	MANİSA	80	69	84	95	78	93

Table A1.4 Inputs and outputs data for the candidate suppliers of "Plastic & Polyester & Glass Materials"

SUPPLIERS	LOCATION	INPUTS		OUTPUTS			
		TC	EX	OTD	AR	SL	DR
1	ISTANBUL	80	90	48	29	57	1
2	İSTANBUL	90	75	22	99	70	99
3	İZMİR	80	90	60	98	78	97
4	İSTANBUL	80	52	52	100	63	68
5	İZMİR	90	45	54	99	62	79
6	İSTANBUL	90	60	72	1	44	91
7	İSTANBUL	50	66	81	80	71	96
8	BURSA	70	76	93	1	53	97
9	KOCAELİ	70	90	34	99	75	99
10	İZMİR	80	50	43	95	62	57
11	İSTANBUL	80	94	38	100	78	93
12	İZMİR	90	45	24	5	29	1
13	İZMİR	90	76	55	70	65	99
14	İSTANBUL	80	90	69	19	59	1
15	İZMİR	60	90	66	100	80	88
16	İSTANBUL	90	95	65	99	86	1
17	İSTANBUL	80	90	89	99	85	1
18	İSTANBUL	90	79	67	94	77	1

Table A1.5 Inputs and outputs data for the candidate suppliers of "Radiator & Intercooler"

SUPPLIERS	LOCATION	INPUTS		OUTPUTS			
		TC	EX	OTD	AR	SL	DR
1	KOCAELİ	70	95	29	100	76	98
2	İSTANBUL	80	81	41	55	60	100
3	İZMİR	60	81	80	98	82	90
4	İZMİR	90	75	64	100	79	92
5	ANKARA	70	75	97	100	87	95

Table A1.6 Inputs and outputs data for the candidate suppliers of "Sawdust Manufacturing & Casting & Forging & Connection Elements & Assembly Parts"

SUPPLIERS	LOCATION	INPUTS		OUTPUTS			
		TC	EX	OTD	AR	SL	DR
1	KOCAELİ	75	95	100	100	95	47
2	İZMİR	80	90	36	74	69	1
3	İZMİR	65	84	41	95	72	96
4	DENİZLİ	70	90	49	100	78	98
5	İZMİR	80	81	60	99	77	48
6	İZMİR	80	89	71	37	64	27
7	İZMİR	40	90	80	100	83	100
8	İZMİR	100	90	88	100	91	100
9	BURSA	70	90	83	100	86	1
10	BURSA	70	75	62	100	76	73
11	İZMİR	80	50	51	79	58	94
12	İZMİR	70	77	38	99	70	28
13	İZMİR	60	78	33	32	49	93
14	İSTANBUL	70	65	70	72	64	67
15	MERSİN	90	95	31	100	78	99
16	İSTANBUL	50	95	52	81	71	22
17	MANİSA	80	76	91	91	82	93
18	İSTANBUL	60	90	77	100	81	96
19	İSTANBUL	60	64	52	28	46	96
20	KOCAELİ	70	90	93	98	90	100
21	ANKARA	50	90	23	94	72	47
22	TEKİRDAĞ	65	95	56	91	76	62
23	İZMİR	90	77	31	38	53	96
24	SAKARYA	80	90	58	100	78	67
25	BURSA	70	90	53	100	75	86
26	İSTANBUL	75	87	85	100	80	99
27	BURSA	50	95	42	100	74	88
28	İSTANBUL	60	94	10	44	57	95
29	İZMİR	75	75	37	86	66	93
30	BURSA	60	90	61	100	80	1
31	İZMİR	60	90	45	99	74	1
32	KAYSERİ	65	75	69	100	80	44
33	ANKARA	60	90	46	100	76	87
34	İZMİR	60	90	59	82	73	25
35	İSTANBUL	40	90	74	89	76	32
36	ÇANAKKALE	60	90	61	100	80	1
37	İZMİR	50	77	68	48	59	1
38	KONYA	80	90	30	100	76	99
39	ESKİŞEHİR	65	95	79	99	88	59
40	DENİZLİ	60	95	72	100	83	87
41	BURSA	55	90	48	99	75	7
42	MANİSA	55	95	25	99	75	1
43	İZMİR	65	83	69	93	78	99
44	İSTANBUL	70	95	60	100	82	94
45	İSTANBUL	65	75	21	4	38	99
46	BURSA	70	90	55	100	79	1
47	ÇANAKKALE	85	45	64	93	60	1
48	BURSA	60	90	93	100	88	67
49	İZMİR	65	70	65	58	60	26
50	SAKARYA	50	75	42	100	66	93

Table A1.7 Inputs and outputs data for the candidate suppliers of "Sheet Iron & Welded Assemblies"

SUPPLIERS	LOCATION	INPUTS		OUTPUTS			
		TC	EX	OTD	AR	SL	DR
1	BURSA	80	90	92	100	87	91
2	BURSA	80	88	63	82	74	80
3	İZMİR	100	71	77	19	55	94
4	İZMİR	90	79	78	96	82	1
5	İSTANBUL	80	75	66	100	76	100
6	ÇANAKKALE	80	81	85	98	83	82
7	MANİSA/SOMA	100	79	85	75	78	50
8	İZMİR/TORBALI	80	76	90	87	81	97
9	AYDIN	90	47	98	98	77	91
10	DENİZLİ	70	58	63	100	69	51
11	BURSA	70	75	17	21	44	97
12	KÜTAHYA	90	82	85	97	87	1
13	İSTANBUL	70	53	66	100	65	1
14	BURSA	70	91	79	100	87	1
15	BURSA	90	77	73	87	74	1
16	ESKİŞEHİR	90	50	62	98	65	92
17	BALIKESİR	90	81	87	97	87	97
18	MUĞLA	90	70	80	100	79	39
19	ÇANAKKALE	90	74	87	58	71	93
20	DENİZLİ	90	90	59	75	74	1
21	ÇANAKKALE	90	59	65	68	62	94
22	BURSA	90	77	92	100	87	76
23	ANTALYA	80	68	87	72	73	93
24	İSTANBUL	80	47	73	34	47	87
25	BURSA	70	90	63	91	79	97
26	BURSA	70	90	66	97	83	86
27	KÜTAHYA	90	86	71	97	85	72
28	DENİZLİ	70	90	77	95	84	1
29	BURSA	70	81	46	100	72	73
30	BURSA	70	77	1	100	68	100

Table A1.8 Inputs and outputs data for the candidate suppliers of "Trim & Rubber Materials"

SUPPLIERS	**LOCATION**	**INPUTS**		**OUTPUTS**			
		TC	**EX**	**OTD**	**AR**	**SL**	**DR**
1	BURSA	60	80	49	100	74	1
2	BURSA	80	90	83	100	85	88
3	SAMSUN	80	71	67	57	65	100
4	BURSA	80	90	64	99	82	1
5	BURSA	80	90	63	100	82	55
6	İZMİR	60	88	86	99	85	98
7	İZMİR	90	45	69	22	43	86
8	BURSA	80	90	90	100	89	96
9	BURSA	80	90	74	95	78	87
10	BURSA	90	86	48	82	72	52
11	KOCAELİ	80	90	63	92	78	100
12	BURSA	80	75	34	100	70	96
13	İZMİR	70	82	57	100	79	67
14	AKSARAY	70	95	85	100	87	1
15	BURSA	90	95	49	74	74	97
16	İSTANBUL	80	90	87	100	88	89
17	İZMİR	90	90	45	89	76	68
18	GEBZE	81	90	50	89	74	96
19	İSTANBUL	80	45	47	1	29	78

APPENDIX A2

THE RELATIVE EFFICIENCY SCORES FOR THE CANDIDATE SUPPLIERS

Table A2.1 The relative efficiency scores for the candidate suppliers of "Air Systems"

SUPPLIERS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1	%102,89	1,000
2	%190,19	1,000
3	%68,72	0,687
4	%69,41	0,694
5	%88,80	0,888
6	%101,88	1,000

Table A2.2 The relative efficiency scores for the candidate suppliers of "Auto Tyres"

SUPPLIERS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1	%83,50	0,835
2	%79,06	0,790
3	%112,53	1,000
4	%127,39	1,000
5	%85,11	0,851

Table A2.3 The relative efficiency scores for the candidate suppliers of "Chemical Materials"

SUPPLIERS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1	%86,83	0,868
2	%138,68	1,000
3	%105,85	1,000
4	%94,38	0,943
5	%91,83	0,918
6	%132,93	1,000

Table A2.4 The relative efficiency scores for the candidate suppliers of "Plastic & Polyester & Glass Materials"

SUPPLIERS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1	%57,18	0,572
2	%84,52	0,845
3	%81,77	0,818
4	%104,18	1,000
5	%129,62	1,000
6	%98,41	0,984
7	%141,14	1,000
8	%99,71	0,997
9	%89,39	0,894
10	%98,77	0,988
11	%82,01	0,820
12	%46,77	0,468
13	%83,61	0,836
14	%62,47	0,625
15	%104,17	1,000
16	%80,69	0,807
17	%85,26	0,853
18	%83,41	0,834

Table A2.5 The relative efficiency scores for the candidate suppliers of "Radiator & Intercooler"

SUPPLIERS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1	%93,33	0,933
2	%97,47	0,974
3	%114,33	1,000
4	%100,00	0,999
5	%130,95	1,000

Table A2.6 The relative efficiency scores for the candidate suppliers of "Sawdust Manufacturing & Casting & Forging & Connection Elements & Assembly Parts"

SUPPLIERS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1	%98,59	0,986
2	%71,49	0,715
3	%88,27	0,883
4	%87,50	0,875
5	%87,34	0,873
6	%70,47	0,705
7	%156,12	1,000
8	%92,50	0,925
9	%93,31	0,933
10	%96,71	0,967
11	%144,39	1,000
12	%89,11	0,891
13	%87,20	0,872
14	%90,44	0,904
15	%79,35	0,793
16	%78,65	0,787
17	%110,92	1,000
18	%92,28	0,923
19	%104,23	1,000
20	%98,93	0,989
21	%86,60	0,866
22	%79,69	0,797
23	%76,60	0,766
24	%82,75	0,828
25	%84,76	0,848
26	%93,71	0,937
27	%88,24	0,882
28	%79,95	0,800
29	%85,13	0,851
30	%89,54	0,895
31	%86,00	0,860
32	%102,33	1,000
33	%88,22	0,882
34	%81,25	0,813
35	%92,50	0,925
36	%89,54	0,895
37	%86,40	0,864
38	%83,83	0,838
39	%92,24	0,922
40	%89,41	0,894
41	%88,57	0,886
42	%85,15	0,851
43	%94,04	0,940
44	%86,69	0,867
45	%91,40	0,914
46	%85,28	0,853
47	%135,83	1,000
48	%103,17	1,000
49	%81,73	0,817
50	%109,01	1,000

Table A2.7 The relative efficiency scores for the candidate suppliers of "Sheet Iron & Welded Assemblies"

SUPPLIERS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1	%105,51	1,000
2	%84,06	0,841
3	%82,65	0,827
4	%88,23	0,882
5	%101,01	1,000
6	%97,99	0,980
7	%78,88	0,789
8	%103,68	1,000
9	%150,49	1,000
10	%107,11	1,000
11	%100,02	1,000
12	%92,13	0,921
13	%105,87	1,000
14	%104,78	1,000
15	%80,49	0,805
16	%98,72	0,987
17	%95,28	0,953
18	%89,69	0,897
19	%89,10	0,891
20	%75,19	0,752
21	%93,07	0,931
22	%95,89	0,959
23	%99,29	0,993
24	%102,76	1,000
25	%109,30	1,000
26	%104,39	1,000
27	%89,68	0,897
28	%97,39	0,974
29	%100,64	1,000
30	%110,96	1,000

Table A2.8 The relative efficiency scores for the candidate suppliers of "Trim & Rubber Materials"

SUPPLIERS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1	%107,53	1,000
2	%97,68	0,976
3	%101,85	1,000
4	%93,57	0,935
5	%93,78	0,937
6	%135,03	1,000
7	%148,59	1,000
8	%101,52	1,000
9	%91,34	0,913
10	%84,90	0,849
11	%90,89	0,908
12	%117,66	1,000
13	%100,93	1,000
14	%94,22	0,942
15	%80,71	0,807
16	%99,14	0,991
17	%86,15	0,861
18	%86,93	0,869
19	%97,20	0,972

APPENDIX A3
THE RESULTS OF PEG FORMULATION AND M_EFF SCORES FOR THE CANDIDATE SUPPLIERS

Table A3.1 The results of PEG formulation and M_EFF scores for the candidate suppliers of "Air Systems"

TEST / TARGET	1	2	3	4	5	6
1	**1,000**	0,952	0,170	0,395	0,808	0,876
2	0,165	**1,000**	0,121	0,245	0,396	0,524
3	0,517	0,994	**0,687**	0,559	0,574	0,573
4	0,470	0,991	0,299	**0,694**	0,712	0,711
5	0,342	0,976	0,187	0,398	**0,888**	0,885
6	0,316	0,964	0,131	0,304	0,622	**1,000**
M_EFF SCORES	**0,468**	**0,980**	**0,266**	**0,432**	**0,667**	**0,761**

Table A3.2 The results of PEG formulation and M_EFF scores for the candidate suppliers of "Auto Tyres"

TEST / TARGET	1	2	3	4	5
1	**0,835**	0,643	0,995	0,886	0,775
2	0,790	**0,790**	0,955	0,897	0,743
3	0,480	0,369	**1,000**	0,887	0,686
4	0,376	0,306	0,783	**1,000**	0,538
5	0,539	0,415	0,989	0,881	**0,851**
M_EFF SCORES	**0,604**	**0,505**	**0,944**	**0,910**	**0,718**

Table A3.3 The results of PEG formulation and M_EFF scores for the candidate suppliers of "Chemical Materials"

TEST / TARGET	1	2	3	4	5	6
1	**0,868**	0,857	0,934	0,896	0,886	0,846
2	0,457	**1,000**	0,713	0,700	0,681	0,657
3	0,641	0,888	**1,000**	0,893	0,773	0,731
4	0,616	0,893	0,915	**0,943**	0,817	0,766
5	0,609	0,869	0,792	0,816	**0,918**	0,842
6	0,484	0,752	0,629	0,648	0,729	**1,000**
M_EFF SCORES	**0,612**	**0,877**	**0,830**	**0,816**	**0,801**	**0,807**

Table A3.4 The results of PEG formulation and M_EFF scores for the candidate suppliers of "Plastic & Polyester & Glass Materials"

TEST / TARGET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	**0,572**	0,233	0,715	0,620	0,553	0,018	0,972	0,023	0,405	0,512	0,434	0,088	0,580	0,375	0,787	0,508	0,572	0,508
2	0,007	**0,845**	0,690	0,653	0,674	0,009	0,776	0,008	0,704	0,547	0,633	0,009	0,590	0,007	0,626	0,007	0,007	0,008
3	0,008	0,267	**0,818**	0,573	0,578	0,007	0,911	0,010	0,464	0,481	0,496	0,007	0,519	0,008	0,742	0,007	0,008	0,007
4	0,008	0,293	0,566	**1,000**	0,875	0,009	0,630	0,007	0,378	0,827	0,404	0,013	0,479	0,008	0,578	0,008	0,008	0,010
5	0,006	0,244	0,495	0,745	**1,000**	0,008	0,551	0,006	0,315	0,649	0,337	0,013	0,419	0,006	0,505	0,006	0,006	0,007
6	0,007	0,241	0,547	0,800	0,738	**0,984**	0,944	0,777	0,310	0,661	0,331	0,011	0,593	0,007	0,601	0,007	0,007	0,008
7	0,007	0,151	0,463	0,401	0,370	0,007	**1,000**	0,009	0,300	0,332	0,293	0,006	0,377	0,007	0,598	0,006	0,007	0,006
8	0,009	0,183	0,543	0,488	0,450	0,600	1,000	**0,997**	0,308	0,403	0,329	0,008	0,459	0,009	0,597	0,008	0,009	0,008
9	0,008	0,450	0,766	0,537	0,555	0,007	0,985	0,009	**0,894**	0,450	0,735	0,007	0,492	0,008	0,795	0,007	0,008	0,007
10	0,010	0,337	0,566	0,965	0,878	0,009	0,630	0,007	0,434	**0,988**	0,464	0,015	0,479	0,010	0,578	0,009	0,010	0,011
11	0,009	0,422	0,804	0,600	0,579	0,007	0,934	0,009	0,766	0,503	**0,820**	0,008	0,510	0,009	0,810	0,008	0,009	0,008
12	0,234	0,257	0,585	0,878	1,001	0,070	0,781	0,055	0,332	0,755	0,355	**0,468**	0,621	0,234	0,644	0,222	0,234	0,267
13	0,007	0,334	0,692	0,646	0,667	0,012	0,933	0,012	0,436	0,542	0,467	0,008	**0,836**	0,007	0,628	0,007	0,007	0,008
14	0,435	0,177	0,543	0,471	0,435	0,029	1,000	0,038	0,308	0,389	0,330	0,146	0,443	**0,625**	0,598	0,523	0,625	0,539
15	0,009	0,222	0,682	0,580	0,517	0,007	0,960	0,009	0,442	0,486	0,432	0,008	0,467	0,009	**1,000**	0,008	0,009	0,008
16	0,250	0,273	0,773	0,665	0,582	0,008	0,939	0,010	0,446	0,601	0,477	0,041	0,571	0,163	0,792	**0,807**	0,842	0,723
17	0,250	0,187	0,575	0,498	0,460	0,008	0,940	0,010	0,326	0,412	0,349	0,038	0,469	0,164	0,633	0,554	**0,853**	0,571
18	0,226	0,274	0,656	0,728	0,672	0,009	0,850	0,009	0,371	0,602	0,398	0,044	0,621	0,148	0,721	0,673	0,732	**0,834**
M_EFF SCORES	**0,114**	**0,300**	**0,638**	**0,658**	**0,644**	**0,100**	**0,874**	**0,111**	**0,441**	**0,563**	**0,449**	**0,052**	**0,529**	**0,100**	**0,680**	**0,187**	**0,220**	**0,197**

Table A3.5 The results of PEG formulation and M_EFF scores for the candidate suppliers of "Radiator & Intercooler"

TEST / TARGET	1	2	3	4	5
1	**0,933**	0,449	1,000	0,681	0,904
2	0,587	**0,974**	0,877	0,797	0,999
3	0,309	0,384	**1,000**	0,533	0,875
4	0,357	0,509	0,905	**0,999**	0,999
5	0,236	0,370	0,764	0,513	**1,000**
M_EFF SCORES	**0,485**	**0,537**	**0,909**	**0,705**	**0,955**

Table A3.6 The results of PEG formulation and M_EFF scores for the candidate suppliers of "Sawdust Manufacturing & Casting & Forging & Connection Elements & Assembly Parts"

TARGET \ TEST	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**0,986**	0,020	0,457	0,510	0,555	0,342	0,833	0,651	0,022	0,655	0,471	0,401	0,384	0,712	0,255
2	0,915	**0,715**	0,799	0,808	0,798	0,358	0,860	0,754	0,715	0,900	0,601	0,829	0,357	0,758	0,547
3	0,375	0,007	**0,883**	0,837	0,359	0,202	0,858	0,598	0,009	0,623	0,578	0,239	0,320	0,572	0,482
4	0,392	0,008	0,784	**0,875**	0,375	0,211	0,875	0,613	0,009	0,652	0,569	0,250	0,323	0,598	0,431
5	0,729	0,016	0,575	0,642	**0,873**	0,297	0,794	0,705	0,016	0,931	0,658	0,536	0,293	0,726	0,385
6	0,930	0,026	0,431	0,481	0,596	**0,705**	0,786	0,699	0,026	0,704	0,506	0,431	0,374	0,794	0,274
7	0,251	0,005	0,315	0,350	0,240	0,135	**1,000**	0,400	0,006	0,417	0,319	0,160	0,213	0,383	0,172
8	0,412	0,009	0,462	0,515	0,493	0,253	0,841	**0,925**	0,009	0,782	0,670	0,303	0,342	0,858	0,309
9	0,871	0,354	0,494	0,551	0,590	0,302	0,899	0,653	**0,933**	0,697	0,502	0,427	0,344	0,672	0,271
10	0,492	0,011	0,571	0,637	0,556	0,301	0,806	0,677	0,011	**0,967**	0,646	0,361	0,298	0,696	0,376
11	0,263	0,006	0,479	0,534	0,315	0,161	0,591	0,591	0,006	0,518	**1,000**	0,193	0,260	0,548	0,320
12	0,729	0,027	0,784	0,770	0,780	0,288	0,770	0,630	0,027	0,900	0,622	**0,891**	0,284	0,648	0,565
13	0,353	0,007	0,831	0,788	0,338	0,190	0,813	0,563	0,008	0,587	0,661	0,225	**0,872**	0,538	0,546
14	0,434	0,010	0,410	0,457	0,520	0,266	0,746	0,796	0,010	0,694	0,576	0,319	0,335	**0,904**	0,274
15	0,376	0,008	0,828	0,829	0,433	0,231	0,837	0,714	0,008	0,741	0,663	0,277	0,309	0,690	**0,793**
16	0,648	0,022	0,477	0,530	0,533	0,225	0,971	0,486	0,026	0,602	0,402	0,411	0,259	0,500	0,261
17	0,404	0,009	0,408	0,455	0,484	0,248	0,742	0,774	0,009	0,690	0,560	0,297	0,343	0,823	0,273
18	0,362	0,007	0,454	0,503	0,346	0,195	0,923	0,554	0,008	0,602	0,459	0,231	0,295	0,552	0,248
19	0,330	0,007	0,601	0,670	0,375	0,202	0,741	0,625	0,007	0,649	0,734	0,242	0,521	0,598	0,397
20	0,434	0,009	0,467	0,521	0,415	0,234	0,851	0,655	0,010	0,659	0,475	0,277	0,373	0,663	0,256
21	0,577	0,012	0,666	0,658	0,553	0,213	0,921	0,461	0,013	0,653	0,436	0,369	0,246	0,474	0,512
22	0,524	0,010	0,584	0,648	0,501	0,263	0,919	0,569	0,012	0,740	0,494	0,334	0,304	0,586	0,319
23	0,304	0,007	0,702	0,669	0,364	0,186	0,683	0,683	0,007	0,598	0,844	0,223	0,637	0,633	0,621
24	0,550	0,012	0,627	0,700	0,593	0,306	0,828	0,662	0,012	0,922	0,616	0,395	0,306	0,681	0,393
25	0,433	0,009	0,703	0,784	0,414	0,233	0,848	0,594	0,010	0,720	0,574	0,276	0,313	0,611	0,386

Table A3.6 (Cont'd)

TEST / TARGET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
26	0,407	0,009	0,468	0,522	0,426	0,240	0,852	0,703	0,009	0,732	0,527	0,284	0,334	0,679	0,285
27	0,314	0,006	0,645	0,630	0,301	0,169	0,931	0,441	0,007	0,523	0,432	0,200	0,235	0,454	0,362
28	0,317	0,006	0,746	0,707	0,303	0,171	0,880	0,505	0,007	0,527	0,594	0,202	0,582	0,484	0,556
29	0,340	0,008	0,784	0,747	0,407	0,208	0,763	0,686	0,008	0,668	0,701	0,250	0,304	0,657	0,563
30	0,716	0,396	0,555	0,616	0,646	0,248	0,895	0,537	0,767	0,729	0,487	0,478	0,286	0,552	0,303
31	0,695	0,482	0,723	0,745	0,645	0,241	0,869	0,521	0,737	0,745	0,506	0,622	0,278	0,536	0,395
32	0,789	0,018	0,531	0,592	0,707	0,301	0,833	0,650	0,019	0,834	0,589	0,511	0,308	0,669	0,324
33	0,381	0,008	0,726	0,756	0,365	0,205	0,882	0,529	0,009	0,634	0,505	0,243	0,282	0,544	0,396
34	0,793	0,024	0,522	0,579	0,620	0,275	0,924	0,595	0,028	0,725	0,484	0,449	0,317	0,611	0,285
35	0,554	0,014	0,315	0,350	0,375	0,192	1,000	0,416	0,017	0,443	0,319	0,271	0,222	0,428	0,172
36	0,716	0,396	0,555	0,616	0,646	0,248	0,895	0,537	0,767	0,729	0,487	0,478	0,286	0,552	0,303
37	0,847	0,286	0,401	0,445	0,476	0,416	0,870	0,559	0,617	0,563	0,405	0,345	0,349	0,635	0,219
38	0,377	0,008	0,851	0,830	0,406	0,229	0,838	0,670	0,008	0,706	0,640	0,271	0,309	0,648	0,745
39	0,637	0,013	0,479	0,531	0,569	0,280	0,918	0,605	0,015	0,672	0,484	0,406	0,323	0,623	0,261
40	0,386	0,008	0,470	0,522	0,370	0,208	0,944	0,536	0,009	0,643	0,469	0,247	0,286	0,552	0,257
41	0,656	0,087	0,640	0,703	0,609	0,228	0,895	0,492	0,099	0,703	0,471	0,551	0,263	0,506	0,350
42	0,630	0,437	0,691	0,675	0,585	0,219	0,907	0,473	0,669	0,675	0,452	0,624	0,252	0,486	0,525
43	0,387	0,008	0,552	0,616	0,370	0,208	0,876	0,617	0,009	0,644	0,565	0,247	0,344	0,591	0,305
44	0,405	0,008	0,638	0,708	0,387	0,218	0,915	0,607	0,009	0,673	0,537	0,258	0,324	0,618	0,348
45	0,343	0,008	0,791	0,754	0,360	0,203	0,769	0,600	0,008	0,626	0,705	0,240	0,826	0,574	0,660
46	0,796	0,489	0,681	0,760	0,727	0,276	0,853	0,597	0,853	0,821	0,548	0,589	0,315	0,614	0,374
47	0,509	0,281	0,343	0,383	0,521	0,201	0,538	0,538	0,500	0,581	0,717	0,347	0,199	0,536	0,229
48	0,561	0,011	0,407	0,452	0,484	0,278	0,860	0,568	0,013	0,571	0,411	0,350	0,320	0,617	0,222
49	0,926	0,024	0,429	0,479	0,613	0,410	0,782	0,719	0,024	0,724	0,521	0,434	0,372	0,809	0,281
50	0,337	0,007	0,731	0,714	0,323	0,181	0,833	0,500	0,008	0,561	0,494	0,215	0,267	0,514	0,410
M_EFF SCORES	**0,547**	**0,125**	**0,637**	**0,689**	**0,581**	**0,365**	**0,966**	**0,750**	**0,317**	**0,864**	**0,758**	**0,588**	**0,590**	**0,877**	**0,663**

Table A3.6 (Cont'd)

TEST / TARGET	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0,462	0,798	0,801	0,345	0,968	0,239	0,552	0,255	0,536	0,552	0,830	0,414	0,100	0,365	0,022
2	0,697	0,850	0,839	0,361	0,933	0,457	0,746	0,326	0,808	0,777	0,858	0,726	0,190	0,730	0,715
3	0,179	0,687	0,824	0,282	0,846	0,403	0,504	0,255	0,501	0,735	0,789	0,716	0,192	0,691	0,009
4	0,186	0,697	0,857	0,286	0,858	0,411	0,524	0,259	0,523	0,768	0,817	0,711	0,171	0,617	0,009
5	0,341	0,802	0,794	0,312	0,778	0,301	0,684	0,298	0,760	0,694	0,821	0,521	0,125	0,574	0,016
6	0,484	0,903	0,756	0,676	0,913	0,226	0,521	0,274	0,570	0,520	0,863	0,391	0,094	0,392	0,026
7	0,176	0,455	0,640	0,187	0,560	0,230	0,382	0,169	0,335	0,379	0,514	0,420	0,083	0,247	0,007
8	0,193	0,987	0,809	0,364	0,907	0,242	0,543	0,362	0,610	0,557	0,841	0,418	0,101	0,467	0,009
9	0,554	0,743	0,866	0,305	0,914	0,259	0,596	0,271	0,570	0,596	0,810	0,447	0,108	0,388	0,686
10	0,230	0,770	0,806	0,316	0,790	0,299	0,648	0,286	0,740	0,689	0,834	0,517	0,124	0,539	0,011
11	0,123	0,651	0,567	0,277	0,591	0,251	0,347	0,312	0,396	0,508	0,605	0,433	0,104	0,484	0,006
12	0,567	0,717	0,770	0,294	0,755	0,461	0,664	0,266	0,770	0,770	0,797	0,729	0,192	0,722	0,027
13	0,169	0,654	0,780	0,763	0,804	0,382	0,477	0,546	0,471	0,691	0,743	0,677	0,219	0,698	0,008
14	0,203	0,977	0,718	0,357	0,867	0,215	0,495	0,311	0,541	0,494	0,820	0,371	0,089	0,414	0,010
15	0,176	0,812	0,812	0,330	0,820	0,397	0,497	0,301	0,566	0,727	0,866	0,705	0,259	0,805	0,008
16	**0,787**	0,553	0,748	0,227	0,680	0,348	0,648	0,205	0,540	0,573	0,591	0,636	0,126	0,373	0,030
17	0,189	**1,000**	0,715	0,365	0,863	0,213	0,492	0,303	0,538	0,492	0,816	0,369	0,089	0,412	0,009
18	0,200	0,630	**0,923**	0,258	0,775	0,276	0,550	0,234	0,483	0,545	0,729	0,477	0,115	0,355	0,010
19	0,154	0,727	0,711	**1,000**	0,741	0,315	0,435	0,397	0,496	0,637	0,759	0,544	0,131	0,569	0,007
20	0,206	0,788	0,819	0,330	**0,989**	0,245	0,564	0,256	0,540	0,564	0,821	0,423	0,102	0,367	0,010
21	0,384	0,524	0,768	0,215	0,645	**0,866**	0,645	0,194	0,576	0,644	0,614	0,843	0,314	0,528	0,015
22	0,283	0,648	0,897	0,266	0,797	0,346	**0,797**	0,240	0,665	0,700	0,727	0,598	0,144	0,456	0,014
23	0,142	0,752	0,655	0,679	0,683	0,321	0,401	**0,766**	0,457	0,587	0,699	0,569	0,202	0,762	0,007
24	0,258	0,753	0,828	0,309	0,811	0,328	0,714	0,280	**0,828**	0,757	0,857	0,568	0,137	0,563	0,012
25	0,206	0,675	0,848	0,277	0,831	0,368	0,579	0,251	0,578	**0,848**	0,791	0,637	0,153	0,553	0,010

Table A3.6 (Cont'd)

TEST / TARGET	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
26	0,191	0,799	0,821	0,328	0,888	0,245	0,537	0,285	0,594	0,565	**0,937**	0,424	0,102	0,408	0,009
27	0,221	0,502	0,735	0,206	0,617	0,471	0,478	0,186	0,420	0,616	0,588	**0,882**	0,175	0,506	0,008
28	0,183	0,587	0,808	0,509	0,722	0,413	0,482	0,461	0,423	0,621	0,667	0,733	**0,800**	0,627	0,008
29	0,159	0,798	0,732	0,325	0,763	0,358	0,448	0,313	0,511	0,656	0,781	0,636	0,184	**0,851**	0,008
30	0,687	0,611	0,895	0,251	0,752	0,337	0,752	0,227	0,638	0,667	0,716	0,584	0,140	0,434	**0,895**
31	0,667	0,593	0,869	0,243	0,730	0,440	0,730	0,220	0,652	0,745	0,695	0,760	0,183	0,566	0,860
32	0,395	0,739	0,833	0,303	0,817	0,278	0,641	0,274	0,683	0,640	0,862	0,481	0,116	0,465	0,019
33	0,211	0,602	0,882	0,247	0,741	0,441	0,580	0,223	0,509	0,746	0,706	0,763	0,184	0,568	0,010
34	0,678	0,677	0,902	0,278	0,833	0,317	0,712	0,251	0,599	0,626	0,713	0,548	0,132	0,408	0,033
35	0,509	0,473	0,642	0,194	0,582	0,230	0,431	0,172	0,363	0,379	0,519	0,420	0,083	0,247	0,019
36	0,687	0,611	0,895	0,251	0,752	0,337	0,752	0,227	0,638	0,667	0,716	0,584	0,140	0,434	0,895
37	0,536	0,723	0,815	0,420	0,844	0,250	0,547	0,219	0,461	0,481	0,720	0,433	0,104	0,313	0,646
38	0,176	0,763	0,813	0,313	0,821	0,398	0,497	0,283	0,567	0,728	0,867	0,706	0,267	0,769	0,008
39	0,344	0,689	0,896	0,282	0,847	0,283	0,654	0,256	0,550	0,574	0,726	0,490	0,118	0,374	0,016
40	0,226	0,610	0,872	0,250	0,751	0,301	0,588	0,226	0,516	0,564	0,689	0,522	0,124	0,368	0,010
41	0,687	0,560	0,820	0,230	0,689	0,425	0,689	0,208	0,615	0,696	0,656	0,734	0,169	0,501	0,116
42	0,696	0,538	0,788	0,221	0,662	0,826	0,662	0,200	0,591	0,669	0,630	0,840	0,312	0,542	0,780
43	0,183	0,717	0,841	0,307	0,876	0,289	0,514	0,277	0,517	0,666	0,815	0,500	0,120	0,437	0,009
44	0,203	0,690	0,904	0,283	0,850	0,351	0,572	0,256	0,541	0,766	0,789	0,607	0,146	0,499	0,010
45	0,160	0,698	0,739	0,960	0,769	0,362	0,452	0,640	0,503	0,662	0,788	0,641	0,347	0,744	0,008
46	0,655	0,679	0,853	0,279	0,836	0,357	0,735	0,252	0,737	0,810	0,796	0,617	0,148	0,536	0,853
47	0,385	0,579	0,538	0,212	0,527	0,180	0,414	0,239	0,453	0,414	0,556	0,311	0,075	0,347	0,477
48	0,311	0,683	0,828	0,280	0,840	0,247	0,556	0,222	0,468	0,488	0,727	0,428	0,103	0,318	0,015
49	0,482	0,907	0,753	0,427	0,909	0,225	0,519	0,281	0,567	0,518	0,860	0,389	0,094	0,403	0,024
50	0,187	0,569	0,833	0,233	0,700	0,421	0,513	0,211	0,450	0,661	0,667	0,747	0,190	0,573	0,009
M_EFF SCORES	**0,654**	**1,019**	**1,134**	**0,710**	**1,161**	**0,749**	**0,989**	**0,730**	**1,019**	**1,106**	**1,243**	**1,091**	**0,710**	**1,065**	**0,734**

Table A3.6 (Cont'd)

TEST / TARGET	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
1	0,022	0,785	0,479	0,554	0,709	0,022	0,026	0,277	0,779	0,710	0,155	0,021	0,779	0,592	0,046	0,022	0,019	0,964	0,629	0,525
2	0,715	0,995	0,788	0,756	0,788	0,715	0,542	0,596	0,864	0,815	0,777	0,470	0,876	0,805	0,046	0,715	0,585	0,912	0,690	0,821
3	0,009	0,405	0,747	0,215	0,275	0,009	0,010	0,525	0,480	0,708	0,060	0,008	0,864	0,764	0,037	0,009	0,007	0,575	0,239	0,907
4	0,009	0,423	0,777	0,223	0,286	0,009	0,010	0,469	0,499	0,736	0,063	0,008	0,876	0,795	0,038	0,009	0,007	0,598	0,250	0,888
5	0,016	0,864	0,602	0,409	0,524	0,016	0,019	0,393	0,744	0,752	0,115	0,016	0,800	0,744	0,038	0,016	0,017	0,794	0,547	0,660
6	0,026	0,813	0,452	0,579	0,727	0,026	0,030	0,295	0,735	0,670	0,181	0,024	0,735	0,558	0,090	0,026	0,025	0,913	0,794	0,495
7	0,007	0,271	0,383	0,167	0,320	0,007	0,008	0,188	0,363	0,580	0,051	0,007	0,531	0,429	0,025	0,006	0,005	0,447	0,160	0,420
8	0,009	0,488	0,484	0,231	0,296	0,009	0,011	0,315	0,517	0,717	0,065	0,009	0,786	0,597	0,044	0,009	0,011	0,620	0,309	0,530
9	0,506	0,835	0,517	0,663	0,825	0,686	0,523	0,295	0,841	0,767	0,540	0,266	0,835	0,639	0,040	0,618	0,536	0,933	0,583	0,567
10	0,011	0,583	0,598	0,276	0,353	0,011	0,013	0,390	0,617	0,763	0,077	0,010	0,813	0,739	0,039	0,011	0,011	0,740	0,369	0,655
11	0,006	0,312	0,501	0,148	0,189	0,006	0,007	0,327	0,330	0,487	0,041	0,006	0,634	0,526	0,034	0,006	0,010	0,396	0,198	0,549
12	0,027	0,924	0,770	0,631	0,685	0,027	0,032	0,602	0,722	0,729	0,191	0,026	0,776	0,729	0,037	0,027	0,026	0,770	0,562	0,862
13	0,008	0,381	0,707	0,203	0,260	0,008	0,009	0,595	0,454	0,670	0,057	0,008	0,857	0,724	0,101	0,008	0,007	0,544	0,225	0,907
14	0,010	0,515	0,429	0,244	0,312	0,010	0,011	0,280	0,545	0,636	0,068	0,009	0,698	0,530	0,044	0,010	0,011	0,653	0,326	0,470
15	0,008	0,446	0,736	0,211	0,271	0,008	0,010	0,810	0,473	0,697	0,059	0,008	0,844	0,753	0,040	0,008	0,008	0,566	0,283	0,850
16	0,030	0,682	0,580	0,664	0,889	0,030	0,036	0,284	0,740	0,767	0,228	0,033	0,665	0,649	0,030	0,026	0,021	0,810	0,433	0,636
17	0,009	0,479	0,427	0,227	0,291	0,009	0,011	0,278	0,508	0,633	0,064	0,009	0,694	0,527	0,045	0,009	0,010	0,608	0,304	0,468
18	0,010	0,391	0,551	0,240	0,308	0,010	0,011	0,270	0,524	0,792	0,067	0,009	0,763	0,616	0,034	0,008	0,007	0,644	0,231	0,604
19	0,007	0,391	0,629	0,185	0,237	0,007	0,009	0,410	0,414	0,611	0,052	0,007	0,795	0,660	0,122	0,007	0,007	0,496	0,248	0,689
20	0,010	0,469	0,489	0,247	0,316	0,010	0,012	0,279	0,553	0,725	0,069	0,009	0,790	0,604	0,043	0,010	0,008	0,663	0,277	0,536
21	0,015	0,624	0,762	0,384	0,590	0,015	0,018	0,571	0,702	0,768	0,117	0,017	0,659	0,658	0,028	0,013	0,011	0,768	0,369	0,794
22	0,014	0,566	0,691	0,339	0,434	0,014	0,016	0,347	0,758	0,870	0,095	0,013	0,815	0,793	0,035	0,012	0,010	0,909	0,334	0,757
23	0,007	0,360	0,594	0,171	0,218	0,007	0,008	0,634	0,382	0,563	0,048	0,006	0,733	0,608	0,083	0,007	0,008	0,457	0,228	0,762
24	0,012	0,653	0,657	0,309	0,395	0,012	0,014	0,428	0,691	0,784	0,087	0,012	0,835	0,784	0,040	0,012	0,012	0,828	0,395	0,720
25	0,010	0,467	0,736	0,247	0,316	0,010	0,012	0,420	0,551	0,803	0,069	0,009	0,849	0,803	0,037	0,010	0,008	0,661	0,276	0,806

Table A3.6 (Cont'd)

TEST / TARGET	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
26	0,009	0,481	0,490	0,229	0,293	0,009	0,011	0,310	0,511	0,727	0,064	0,009	0,797	0,606	0,043	0,009	0,008	0,613	0,284	0,537
27	0,008	0,339	0,727	0,209	0,339	0,008	0,010	0,394	0,455	0,727	0,064	0,009	0,631	0,630	0,027	0,007	0,006	0,560	0,200	0,787
28	0,008	0,342	0,733	0,211	0,281	0,008	0,010	0,625	0,459	0,725	0,062	0,008	0,770	0,678	0,067	0,007	0,006	0,564	0,202	0,940
29	0,008	0,403	0,663	0,191	0,244	0,008	0,009	0,575	0,426	0,628	0,053	0,007	0,819	0,679	0,040	0,008	0,008	0,511	0,255	0,851
30	0,660	0,826	0,675	0,734	0,797	0,895	0,502	0,330	0,818	0,848	0,704	0,347	0,768	0,755	0,033	0,692	0,474	0,895	0,479	0,739
31	**0,860**	0,802	0,869	0,712	0,773	0,860	0,487	0,430	0,794	0,823	0,860	0,453	0,746	0,745	0,032	0,737	0,492	0,869	0,465	0,920
32	0,019	**1,000**	0,556	0,473	0,606	0,019	0,022	0,353	0,782	0,789	0,133	0,018	0,840	0,686	0,040	0,019	0,017	0,833	0,580	0,609
33	0,010	0,412	**0,882**	0,253	0,324	0,010	0,012	0,431	0,552	0,836	0,071	0,010	0,757	0,756	0,033	0,009	0,007	0,679	0,243	0,919
34	0,033	0,822	0,634	**0,813**	0,846	0,033	0,038	0,310	0,905	0,876	0,228	0,031	0,802	0,709	0,037	0,028	0,023	0,980	0,531	0,694
35	0,019	0,531	0,383	0,482	**0,925**	0,019	0,023	0,188	0,608	0,600	0,147	0,021	0,531	0,429	0,026	0,017	0,014	0,693	0,371	0,420
36	0,660	0,826	0,675	0,734	0,797	**0,895**	0,502	0,330	0,818	0,848	0,704	0,347	0,768	0,755	0,033	0,692	0,474	0,895	0,479	0,739
37	0,476	0,674	0,487	0,625	0,804	0,646	**0,864**	0,238	0,772	0,741	0,522	0,257	0,674	0,545	0,055	0,499	0,478	0,985	0,635	0,534
38	0,008	0,447	0,736	0,212	0,271	0,008	0,010	**0,838**	0,473	0,698	0,059	0,008	0,845	0,754	0,040	0,008	0,008	0,567	0,271	0,873
39	0,016	0,688	0,567	0,412	0,528	0,016	0,019	0,284	**0,922**	0,840	0,115	0,016	0,805	0,650	0,037	0,015	0,012	0,973	0,406	0,621
40	0,010	0,417	0,571	0,257	0,347	0,010	0,012	0,279	0,560	**0,894**	0,076	0,010	0,767	0,639	0,033	0,009	0,007	0,688	0,247	0,626
41	0,116	0,757	0,778	0,673	0,797	0,116	0,139	0,381	0,750	0,820	**0,886**	0,120	0,704	0,703	0,030	0,099	0,082	0,820	0,439	0,853
42	0,770	0,727	0,788	0,646	0,808	0,780	0,454	0,591	0,720	0,788	0,851	**0,851**	0,676	0,675	0,029	0,669	0,441	0,788	0,422	0,824
43	0,009	0,418	0,578	0,219	0,280	0,009	0,010	0,332	0,489	0,722	0,061	0,008	**0,940**	0,714	0,040	0,009	0,007	0,587	0,247	0,633
44	0,010	0,437	0,702	0,243	0,312	0,010	0,011	0,379	0,544	0,802	0,068	0,009	0,868	**0,867**	0,037	0,009	0,008	0,652	0,258	0,769
45	0,008	0,406	0,669	0,192	0,246	0,008	0,009	0,743	0,430	0,634	0,054	0,007	0,826	0,685	**0,914**	0,008	0,007	0,515	0,240	0,859
46	0,698	0,919	0,713	0,699	0,759	0,853	0,479	0,407	0,800	0,808	0,744	0,367	0,854	0,808	0,037	**0,853**	0,534	0,853	0,533	0,782
47	0,352	0,645	0,359	0,441	0,478	0,477	0,302	0,234	0,504	0,509	0,375	0,185	0,542	0,444	0,026	0,430	**1,000**	0,538	0,401	0,394
48	0,015	0,606	0,495	0,373	0,478	0,015	0,017	0,242	0,784	0,733	0,104	0,014	0,685	0,553	0,037	0,013	0,011	**1,000**	0,358	0,542
49	0,024	0,809	0,450	0,577	0,723	0,024	0,029	0,293	0,732	0,667	0,171	0,023	0,731	0,556	0,053	0,024	0,024	0,909	**0,817**	0,493
50	0,009	0,364	0,780	0,224	0,287	0,009	0,010	0,446	0,488	0,739	0,063	0,008	0,715	0,714	0,031	0,008	0,006	0,600	0,215	**1,000**
M_EFF SCORES	**0,732**	**1,200**	**1,256**	**1,046**	**1,160**	**0,852**	**0,831**	**1,142**	**1,370**	**1,501**	**1,012**	**0,905**	**1,592**	**1,517**	**0,941**	**1,029**	**1,030**	**1,644**	**1,330**	**1,663**

Table A3.7 The results of PEG formulation and M_EFF scores for the candidate suppliers of "Sheet Iron & Welded Assemblies"

TEST / TARGET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**1,000**	0,685	0,152	0,010	0,717	0,901	0,440	0,870	0,787	0,641	0,211	0,010	0,013	0,011	0,010
2	0,935	**0,841**	0,156	0,009	0,864	0,862	0,421	0,892	0,778	0,613	0,246	0,009	0,012	0,010	0,009
3	0,632	0,546	**0,827**	0,008	0,671	0,632	0,395	0,797	0,890	0,549	0,173	0,008	0,012	0,007	0,008
4	0,806	0,640	0,157	**0,882**	0,786	0,871	0,620	0,831	0,828	0,916	0,202	0,850	0,899	0,766	0,796
5	0,758	0,682	0,152	0,009	**1,000**	0,759	0,400	0,859	0,809	0,583	0,210	0,009	0,011	0,008	0,009
6	0,900	0,669	0,152	0,011	0,761	**0,980**	0,478	0,870	0,808	0,697	0,212	0,011	0,014	0,011	0,011
7	0,750	0,525	0,200	0,016	0,645	0,770	**0,789**	0,852	0,865	0,797	0,166	0,015	0,023	0,014	0,016
8	0,792	0,605	0,175	0,009	0,733	0,793	0,412	**1,000**	0,834	0,601	0,191	0,009	0,012	0,009	0,009
9	0,490	0,343	0,128	0,007	0,422	0,503	0,327	0,549	**1,000**	0,454	0,109	0,006	0,010	0,006	0,007
10	0,644	0,540	0,133	0,014	0,773	0,702	0,525	0,664	0,762	**1,000**	0,162	0,014	0,020	0,012	0,015
11	0,782	0,703	0,633	0,008	0,902	0,740	0,361	0,875	0,730	0,526	**1,000**	0,008	0,010	0,008	0,008
12	0,839	0,636	0,162	0,845	0,782	0,890	0,641	0,891	0,815	0,878	0,201	**0,921**	0,885	0,771	0,783
13	0,589	0,494	0,133	0,644	0,707	0,641	0,503	0,607	0,762	0,872	0,148	0,627	**1,000**	0,582	0,599
14	0,875	0,698	0,133	0,733	0,731	0,835	0,525	0,761	0,688	0,793	0,210	0,754	0,747	**1,000**	0,662
15	0,792	0,608	0,158	0,785	0,747	0,858	0,625	0,816	0,838	0,893	0,192	0,756	0,909	0,681	**0,805**
16	0,542	0,469	0,135	0,007	0,671	0,543	0,340	0,576	0,976	0,472	0,141	0,007	0,010	0,006	0,007
17	0,805	0,635	0,168	0,010	0,781	0,806	0,442	0,911	0,843	0,644	0,201	0,010	0,013	0,009	0,010
18	0,698	0,562	0,153	0,020	0,691	0,760	0,596	0,719	0,874	0,853	0,176	0,020	0,030	0,018	0,021
19	0,717	0,543	0,263	0,009	0,667	0,718	0,431	0,897	0,872	0,623	0,172	0,009	0,012	0,008	0,009
20	0,884	0,769	0,171	0,752	0,869	0,937	0,677	0,926	0,782	0,902	0,253	0,752	0,849	0,744	0,752
21	0,591	0,531	0,216	0,007	0,744	0,592	0,370	0,746	0,901	0,514	0,192	0,007	0,011	0,006	0,008
22	0,820	0,575	0,164	0,012	0,706	0,842	0,568	0,845	0,849	0,827	0,182	0,012	0,016	0,011	0,013
23	0,734	0,556	0,210	0,009	0,683	0,735	0,427	0,919	0,864	0,622	0,176	0,009	0,012	0,008	0,009
24	0,546	0,461	0,370	0,007	0,567	0,547	0,342	0,690	0,930	0,475	0,146	0,007	0,010	0,006	0,007
25	0,821	0,722	0,146	0,008	0,842	0,740	0,361	0,837	0,730	0,526	0,231	0,008	0,010	0,010	0,008
26	0,902	0,740	0,137	0,009	0,801	0,834	0,407	0,785	0,722	0,593	0,216	0,009	0,012	0,012	0,009
27	0,877	0,741	0,158	0,012	0,902	0,930	0,561	0,905	0,813	0,817	0,223	0,012	0,016	0,012	0,012
28	0,883	0,697	0,136	0,740	0,731	0,842	0,538	0,780	0,694	0,797	0,215	0,758	0,754	0,963	0,667
29	0,875	0,718	0,133	0,011	0,875	0,858	0,479	0,761	0,762	0,699	0,210	0,011	0,014	0,012	0,011
30	0,779	0,700	0,133	0,008	0,875	0,718	0,350	0,761	0,708	0,510	0,210	0,008	0,010	0,008	0,008
M_EFF SCORES	**0,769**	**0,621**	**0,205**	**0,187**	**0,755**	**0,771**	**0,478**	**0,806**	**0,817**	**0,689**	**0,219**	**0,188**	**0,212**	**0,191**	**0,177**

Table A3.7 (Cont'd)

TEST / TARGET	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0,599	0,841	0,381	0,516	0,010	0,604	0,742	0,720	0,340	0,685	0,717	0,686	0,011	0,556	0,012
2	0,657	0,879	0,364	0,529	0,009	0,620	0,710	0,738	0,349	0,822	0,861	0,673	0,010	0,667	0,015
3	0,740	0,748	0,348	0,785	0,007	0,776	0,617	0,854	0,883	0,534	0,559	0,523	0,007	0,433	0,010
4	0,699	0,869	0,850	0,533	0,586	0,625	0,919	0,744	0,351	0,625	0,655	0,737	0,764	0,507	0,012
5	0,760	0,862	0,347	0,516	0,008	0,604	0,676	0,720	0,340	0,758	0,717	0,628	0,008	0,645	0,015
6	0,635	0,862	0,414	0,516	0,011	0,604	0,807	0,720	0,340	0,654	0,685	0,728	0,011	0,530	0,012
7	0,639	0,788	0,684	0,651	0,014	0,670	0,876	0,858	0,447	0,513	0,538	0,605	0,014	0,416	0,010
8	0,612	0,859	0,357	0,593	0,009	0,642	0,696	0,828	0,391	0,591	0,619	0,656	0,009	0,480	0,011
9	0,595	0,515	0,288	0,376	0,006	0,528	0,510	0,508	0,347	0,336	0,352	0,396	0,006	0,272	0,006
10	0,733	0,695	0,595	0,451	0,013	0,529	0,753	0,614	0,298	0,586	0,625	0,654	0,013	0,523	0,012
11	0,738	0,778	0,313	0,746	0,008	0,754	0,609	0,839	0,785	0,833	0,739	0,577	0,009	0,697	0,057
12	0,672	0,921	0,836	0,551	0,582	0,646	0,921	0,769	0,363	0,622	0,652	0,734	0,760	0,505	0,012
13	0,731	0,635	0,757	0,415	0,442	0,529	0,688	0,561	0,298	0,536	0,571	0,598	0,559	0,456	0,010
14	0,581	0,754	0,706	0,451	0,581	0,529	0,778	0,630	0,298	0,797	0,835	0,699	0,950	0,582	0,013
15	0,684	0,853	0,859	0,537	0,557	0,629	0,925	0,749	0,354	0,594	0,623	0,701	0,689	0,482	0,011
16	**0,987**	0,603	0,299	0,395	0,006	0,580	0,529	0,533	0,364	0,509	0,513	0,449	0,006	0,452	0,010
17	0,679	**0,953**	0,383	0,570	0,009	0,668	0,747	0,796	0,376	0,621	0,651	0,666	0,009	0,504	0,012
18	0,695	0,752	**0,897**	0,492	0,018	0,610	0,815	0,665	0,343	0,549	0,576	0,648	0,018	0,446	0,010
19	0,635	0,814	0,374	**0,891**	0,008	0,666	0,700	0,970	0,588	0,531	0,556	0,594	0,008	0,430	0,010
20	0,661	0,884	0,803	0,582	**0,752**	0,630	0,884	0,812	0,384	0,803	0,841	0,864	0,752	0,651	0,015
21	0,888	0,700	0,326	0,633	0,006	**0,931**	0,577	0,799	0,524	0,592	0,558	0,489	0,006	0,480	0,011
22	0,646	0,862	0,492	0,556	0,011	0,652	**0,959**	0,777	0,367	0,562	0,589	0,663	0,011	0,456	0,010
23	0,629	0,834	0,370	0,711	0,008	0,659	0,717	**0,993**	0,469	0,543	0,569	0,608	0,008	0,441	0,010
24	0,755	0,647	0,301	0,679	0,006	0,709	0,533	0,739	**1,000**	0,451	0,472	0,452	0,006	0,366	0,008
25	0,640	0,778	0,313	0,496	0,008	0,581	0,609	0,692	0,327	**1,000**	0,887	0,577	0,010	0,730	0,016
26	0,609	0,778	0,353	0,465	0,009	0,545	0,687	0,649	0,307	0,938	**1,000**	0,651	0,012	0,697	0,015
27	0,686	0,897	0,486	0,536	0,012	0,629	0,918	0,749	0,354	0,761	0,797	**0,897**	0,012	0,617	0,014
28	0,586	0,774	0,712	0,463	0,580	0,542	0,785	0,646	0,305	0,797	0,835	0,699	**0,974**	0,582	0,013
29	0,702	0,754	0,416	0,451	0,011	0,529	0,778	0,630	0,298	0,819	0,873	0,754	0,012	**1,000**	0,022
30	0,716	0,754	0,303	0,451	0,008	0,529	0,591	0,630	0,298	0,779	0,736	0,560	0,009	0,694	**1,000**
M_EFF SCORES	**0,686**	**0,788**	**0,498**	**0,551**	**0,143**	**0,625**	**0,735**	**0,731**	**0,416**	**0,658**	**0,673**	**0,639**	**0,189**	**0,543**	**0,046**

Table A3.8 The results of PEG formulation and M_EFF scores for the candidate suppliers of "Trim & Rubber Materials"

TEST / TARGET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	**1,000**	0,750	0,428	0,743	0,750	0,900	0,147	0,750	0,713	0,547	0,690	0,520	0,857	0,842	0,493	0,750	0,593	0,659	0,008
2	0,012	**0,976**	0,556	0,011	0,610	0,988	0,191	0,976	0,870	0,502	0,741	0,400	0,736	0,011	0,512	0,976	0,470	0,581	0,010
3	0,009	0,694	**1,000**	0,008	0,434	0,791	0,343	0,757	0,686	0,429	0,742	0,480	0,580	0,007	0,547	0,702	0,530	0,589	0,018
4	0,805	0,944	0,538	**0,935**	0,920	0,956	0,185	0,944	0,889	0,623	0,869	0,497	0,914	0,886	0,621	0,944	0,584	0,721	0,009
5	0,019	0,937	0,534	0,017	**0,937**	0,949	0,183	0,937	0,890	0,635	0,862	0,506	0,930	0,016	0,616	0,937	0,595	0,734	0,009
6	0,010	0,673	0,432	0,008	0,421	**1,000**	0,148	0,735	0,645	0,354	0,549	0,297	0,568	0,009	0,380	0,681	0,349	0,431	0,008
7	0,007	0,512	0,615	0,006	0,320	0,583	**1,000**	0,558	0,506	0,316	0,457	0,296	0,428	0,006	0,336	0,517	0,326	0,362	0,045
8	0,012	0,917	0,570	0,010	0,573	0,977	0,196	**1,000**	0,822	0,474	0,700	0,378	0,695	0,010	0,484	0,927	0,444	0,549	0,010
9	0,012	0,923	0,548	0,010	0,577	0,973	0,188	0,961	**0,913**	0,485	0,777	0,419	0,772	0,010	0,537	0,934	0,494	0,609	0,010
10	0,018	0,958	0,664	0,016	0,858	0,980	0,228	0,989	0,879	**0,849**	0,879	0,677	0,977	0,015	0,694	0,989	0,761	0,834	0,012
11	0,010	0,799	0,563	0,009	0,499	0,910	0,193	0,872	0,790	0,420	**0,908**	0,490	0,668	0,009	0,628	0,808	0,549	0,712	0,010
12	0,010	0,764	0,570	0,009	0,477	0,844	0,196	0,833	0,755	0,472	0,767	**1,000**	0,638	0,008	0,584	0,773	0,590	0,742	0,010
13	0,015	0,875	0,499	0,013	0,718	0,923	0,171	0,875	0,831	0,604	0,805	0,522	**1,000**	0,013	0,576	0,875	0,614	0,758	0,009
14	0,634	0,805	0,470	0,621	0,611	0,994	0,161	0,824	0,718	0,414	0,611	0,330	0,632	**0,942**	0,422	0,824	0,388	0,479	0,008
15	0,010	0,773	0,699	0,009	0,483	0,880	0,240	0,843	0,764	0,433	0,878	0,630	0,646	0,008	**0,807**	0,782	0,566	0,843	0,012
16	0,013	0,945	0,565	0,011	0,612	0,979	0,194	0,991	0,843	0,486	0,718	0,387	0,713	0,011	0,496	**0,991**	0,456	0,563	0,010
17	0,014	0,963	0,620	0,013	0,696	0,980	0,213	0,967	0,884	0,658	0,884	0,732	0,931	0,012	0,678	0,967	**0,861**	0,838	0,011
18	0,010	0,797	0,564	0,009	0,498	0,907	0,193	0,869	0,788	0,424	0,898	0,598	0,666	0,009	0,650	0,806	0,554	**0,869**	0,010
19	0,007	0,548	0,790	0,006	0,343	0,624	0,953	0,598	0,542	0,339	0,623	0,422	0,458	0,006	0,480	0,555	0,424	0,517	**0,972**
M_EFF SCORES	**0,138**	**0,819**	**0,591**	**0,130**	**0,597**	**0,902**	**0,280**	**0,857**	**0,775**	**0,498**	**0,756**	**0,504**	**0,727**	**0,149**	**0,555**	**0,828**	**0,534**	**0,652**	**0,063**

APPENDIX A4

DATA ON LOCATION AND CAPACITY FOR THE CANDIDATE SUPPLIERS

Table A4.1 Location and capacity data for the candidate suppliers of "Air Systems"

SUPPLIERS	LOC	CAP
1	88	54117
2	86	46872
3	91	33967
4	86	51948
5	100	50529
6	87	53631

Table A4.2 Location and capacity data for the candidate suppliers of "Auto Tyres"

SUPPLIERS	LOC	CAP
1	88	32523
2	88	33632
3	87	39662
4	100	33683
5	87	35632

Table A4.3 Location and capacity data for the candidate suppliers of "Chemical Materials"

SUPPLIERS	LOC	CAP
1	100	222014
2	99	246599
3	87	221055
4	100	232714
5	100	235735
6	99	217108

Table A4.4 Location and capacity data for the candidate suppliers of "Plastic & Polyester & Glass Materials"

SUPPLIERS	LOC	CAP
1	87	511247
2	87	626448
3	100	759840
4	87	560965
5	100	695856
6	87	399349
7	87	719904
8	91	477241
9	88	675042
10	100	554578
11	87	605862
12	100	260045
13	100	580813
14	87	530949
15	100	715028
16	87	665856
17	87	625128
18	87	687222

Table A4.5 Location and capacity data for the candidate suppliers of "Radiator & Intercooler"

SUPPLIERS	LOC	CAP
1	88	9756
2	87	7720
3	100	10587
4	100	10135
5	86	8856

Table A4.6 Location and capacity data for the candidate suppliers of "Sawdust Manufacturing & Casting & Forging & Connection Elements & Assembly Parts"

SUPPLIERS	LOC	CAP
1	88	1162620
2	100	1018401
3	100	1065380
4	94	1301388
5	100	1135040
6	100	948804
7	100	1344804
8	100	1096572
9	91	1138080
10	91	1124412
11	100	847532
12	100	1034151
13	100	715948
14	87	934438
15	78	1151707
16	87	1040021
17	99	1207491
18	87	1189659
19	87	670762
20	88	1330646
21	86	1059127
22	86	1118376
23	100	775982
24	87	1153733
25	91	1110357
26	87	1172190
27	91	1086781
28	87	837304
29	100	976825
30	91	1182235
31	100	1086562
32	78	1183454
33	86	1119144
34	100	1077215
35	87	1117101
36	92	1180329
37	100	871007
38	86	1113509
39	89	1150932
40	94	1215654
41	91	1100280
42	99	1104369
43	100	1265784
44	87	1200285
45	87	565972
46	91	1155163
47	92	887449
48	91	1298079
49	100	885480
50	87	971770

Table A4.7 Location and capacity data for the candidate suppliers of "Sheet Iron & Welded Assemblies"

SUPPLIERS	LOC	CAP
1	91	1746690
2	91	1484216
3	100	1107478
4	100	1636877
5	87	1519565
6	92	1658427
7	96	1565065
8	98	1615083
9	97	1774032
10	94	1388605
11	91	877511
12	92	1733323
13	87	1307044
14	91	1386936
15	91	1487359
16	89	1304417
17	95	1733845
18	93	1586403
19	92	1424760
20	94	1479584
21	92	1234877
22	91	1741756
23	89	1453275
24	87	942811
25	91	1590756
26	91	1660637
27	92	1700747
28	94	1674708
29	91	1444444
30	91	1357024

Table A4.8 Location and capacity data for the candidate suppliers of "Trim & Rubber Materials"

SUPPLIERS	LOC	CAP
1	91	740081
2	91	846149
3	75	643339
4	91	817889
5	91	815158
6	100	848307
7	100	429707
8	91	888423
9	91	775360
10	91	716609
11	88	776291
12	91	697281
13	100	786923
14	82	860506
15	91	732104
16	87	873380
17	100	752067
18	89	737764
19	87	286639

APPENDIX B1

DATA ON INPUT AND OUTPUT MEASURES FOR THE CANDIDATE DISTRIBUTORS

Table B1.1 Inputs and outputs data for the candidate distributors of "Adana"

DISTRIBUTORS	LOCATION	INPUTS	OUTPUTS		
		OC	OTD	SL	AHO
1	ADANA	80	30	90	95
2	MERSİN	70	45	90	95
3	ADANA	75	84	50	74
4	GAZİANTEP	60	28	67	81
5	İSKENDERUN	55	27	90	95
6	K.MARAŞ	70	44	90	71
7	KAYSERİ	65	26	90	90
8	ADANA	65	83	95	98
9	NEVŞEHİR	70	88	52	76
10	NİĞDE	70	72	80	89

Table B1.2 Inputs and outputs data for the candidate distributors of "Diyarbakır"

DISTRIBUTORS	LOCATION	INPUTS	OUTPUTS		
		OC	OTD	SL	AHO
1	ADIYAMAN	80	69	90	84
2	ELAZIĞ	80	85	81	89
3	DİYARBAKIR	100	88	50	41
4	BATMAN	100	85	79	77
5	VAN	80	90	76	81
6	ŞANLIURFA	90	98	47	73
7	MALATYA	70	63	58	79

Table B1.3 Inputs and outputs data for the candidate distributors of "İstanbul"

DISTRIBUTORS	LOCATION	INPUTS	OUTPUTS		
		OC	OTD	SL	AHO
1	SAKARYA	75	79	90	70
2	BURSA	60	62	90	95
3	BURSA	60	30	90	93
4	İSTANBUL	60	80	81	90
5	İSTANBUL	90	64	75	87
6	İSTANBUL	50	39	90	82
7	İSTANBUL	50	51	71	86
8	İSTANBUL	80	63	77	39
9	İSTANBUL/KADIKÖY	50	68	77	62
10	TEKİRDAĞ	70	97	75	88

Table B1.4 Inputs and outputs data for the candidate distributors of "İzmir"

DISTRIBUTORS	LOCATION	INPUTS	OUTPUTS		
		OC	OTD	SL	AHO
1	ANTALYA	60	21	49	27
2	ANTALYA/SERİK	80	79	89	94
3	ANTALYA	80	84	69	84
4	ANTALYA	50	40	77	74
5	AYDIN	70	28	75	87
6	BALIKESİR/BURHANİY	80	68	73	73
7	BALIKESİR	40	70	75	47
8	İZMİR	51	58	95	98
9	ÇANAKKALE/ÇAN	65	74	90	95
10	ÇANAKKALE	51	29	90	90
11	DENİZLİ	60	45	69	69
12	İZMİR	60	31	90	46
13	İZMİR	50	87	90	95
14	İZMİR/TORBALI	70	77	73	78
15	ANTALYA	40	85	86	93
16	İZMİR	70	80	95	95
17	İZMİR	80	83	76	77
18	KÜTAHYA	80	41	95	98
19	MUĞLA/MARMARİS	75	73	90	79
20	MANİSA/SOMA	70	43	95	98
21	MUĞLA/MARMARİS	60	61	75	88
22	UŞAK	80	58	90	86

Table B1.5 Inputs and outputs data for the candidate distributors of "Samsun"

DISTRIBUTORS	LOCATION	INPUTS	OUTPUTS		
		OC	OTD	SL	AHO
1	ERZURUM	70	61	88	94
2	SİVAS	70	84	80	90
3	TRABZON	90	96	75	88
4	TOKAT	90	85	82	90
5	ÇORUM	70	66	53	76
6	SAMSUN	70	79	91	95

APPENDIX B2

THE RELATIVE EFFICIENCY SCORES FOR THE CANDIDATE DISTRIBUTORS

Table B2.1 The relative efficiency scores for the candidate distributors of the region of "Adana"

DISTRIBUTORS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1	%69,31	0,693
2	%82,42	0,824
3	%87,71	0,877
4	%79,40	0,794
5	%114,56	1,000
6	%81,67	0,816
7	%84,62	0,846
8	%126,19	1,000
9	%98,45	0,984
10	%83,61	0,836

Table B2.2 The relative efficiency scores for the candidate distributors of the region of "Diyarbakır"

DISTRIBUTORS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1	%111,11	1,000
2	%105,74	1,000
3	%78,22	0,782
4	%79,04	0,790
5	%105,29	1,000
6	%96,79	0,967
7	%101,44	1,000

Table B2.3 The relative efficiency scores for the candidate distributors of the region of "İstanbul"

DISTRIBUTORS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1	%77,79	0,777
2	%98,26	0,982
3	%92,41	0,924
4	%106,17	1,000
5	%60,19	0,601
6	%118,20	1,000
7	%107,37	1,000
8	%61,20	0,611
9	%108,70	1,000
10	%101,89	1,000

Table B2.4 The relative efficiency scores for the candidate distributors of the region of "İzmir"

DISTRIBUTORS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1	%37,98	0,379
2	%51,74	0,517
3	%49,41	0,494
4	%71,63	0,716
5	%53,46	0,534
6	%42,44	0,424
7	%87,21	0,872
8	%86,64	0,866
9	%64,40	0,644
10	%82,08	0,820
11	%53,49	0,534
12	%69,77	0,697
13	%83,72	0,837
14	%51,76	0,517
15	%122,36	1,000
16	%63,12	0,631
17	%48,82	0,488
18	%55,23	0,552
19	%55,81	0,558
20	%63,12	0,631
21	%63,08	0,630
22	%52,33	0,523

Table B2.5 The relative efficiency scores for the candidate distributors of the region of "Samsun"

DISTRIBUTORS	EMS RESULTS	RELATIVE EFFICIENCY SCORES
1	%98,95	0,989
2	%106,33	1,000
3	%88,89	0,888
4	%79,01	0,790
5	%81,61	0,816
6	%108,48	1,000

APPENDIX B3
THE RESULTS OF PEG FORMULATION AND M_EFF SCORES FOR THE CANDIDATE DISTRIBUTORS

Table B3.1 The results of PEG formulation and M_EFF scores for the candidate distributors of the region of "Adana"

TARGET \ TEST	1	2	3	4	5	6	7	8	9	10
1	**0,693**	0,792	0,411	0,688	0,907	0,592	0,739	0,880	0,458	0,704
2	0,481	**0,824**	0,427	0,598	0,629	0,616	0,513	0,915	0,476	0,732
3	0,294	0,503	**0,877**	0,365	0,384	0,492	0,313	1,000	0,965	0,805
4	0,638	0,798	0,474	**0,794**	0,835	0,597	0,681	0,887	0,528	0,748
5	0,688	0,786	0,407	0,682	**1,000**	0,587	0,802	0,873	0,454	0,698
6	0,487	0,816	0,423	0,606	0,637	**0,816**	0,519	0,928	0,471	0,725
7	0,687	0,786	0,407	0,682	1,000	0,620	**0,846**	0,893	0,454	0,698
8	0,294	0,503	0,456	0,365	0,384	0,492	0,313	**1,000**	0,508	0,782
9	0,294	0,503	0,877	0,365	0,384	0,492	0,313	0,999	**0,984**	0,805
10	0,305	0,523	0,488	0,379	0,399	0,511	0,325	0,991	0,543	**0,836**
M_EFF SCORES	**0,486**	**0,683**	**0,525**	**0,553**	**0,656**	**0,581**	**0,536**	**0,937**	**0,584**	**0,753**

Table B3.2 The results of PEG formulation and M_EFF scores for the candidate distributors of the region of "Diyarbakır"

TARGET \ TEST	1	2	3	4	5	6	7
1	**1,000**	0,900	0,390	0,702	0,844	0,464	0,737
2	0,812	**1,000**	0,369	0,692	0,910	0,516	0,818
3	0,766	0,944	**0,782**	0,755	1,000	0,817	0,800
4	0,802	0,988	0,421	**0,790**	0,950	0,522	0,829
5	0,767	0,944	0,405	0,756	**1,000**	0,550	0,800
6	0,766	0,944	0,489	0,755	0,999	**0,967**	0,799
7	0,930	0,986	0,363	0,682	0,897	0,630	**1,000**
M_EFF SCORES	**0,835**	**0,958**	**0,460**	**0,733**	**0,943**	**0,638**	**0,826**

Table B3.3 The results of PEG formulation and M_EFF scores for the candidate distributors of the region of "İstanbul"

TARGET \ TEST	1	2	3	4	5	6	7	8	9	10
1	**0,777**	0,762	0,369	0,874	0,525	0,575	0,752	0,406	0,997	0,694
2	0,579	**0,982**	0,475	0,884	0,546	0,741	0,930	0,302	0,769	0,701
3	0,556	0,924	**0,924**	0,832	0,513	0,978	0,875	0,291	0,739	0,660
4	0,622	0,775	0,375	**1,000**	0,533	0,585	0,765	0,325	0,827	0,794
5	0,580	0,873	0,423	0,933	**0,601**	0,659	0,862	0,303	0,771	0,773
6	0,569	0,833	0,641	0,750	0,463	**1,000**	0,789	0,297	0,756	0,595
7	0,543	0,921	0,490	0,872	0,562	0,765	**1,000**	0,283	0,721	0,731
8	0,762	0,802	0,388	0,857	0,529	0,605	0,791	**0,611**	0,978	0,680
9	0,753	0,760	0,368	0,877	0,523	0,574	0,750	0,393	**1,000**	0,696
10	0,742	0,746	0,361	0,962	0,513	0,563	0,736	0,388	0,981	**1,000**
M_EFF SCORES	**0,648**	**0,838**	**0,481**	**0,884**	**0,531**	**0,704**	**0,825**	**0,360**	**0,854**	**0,732**

Table B3.4 The results of PEG formulation and M_EFF scores for the candidate distributors of the region of "Samsun"

TARGET \ TEST	1	2	3	4	5	6
1	**0,989**	0,899	0,656	0,717	0,596	1,000
2	0,726	**1,000**	0,729	0,778	0,663	0,940
3	0,725	0,999	**0,888**	0,786	0,785	0,940
4	0,729	0,991	0,723	**0,790**	0,656	0,944
5	0,754	0,966	0,735	0,752	**0,816**	0,977
6	0,772	0,879	0,641	0,701	0,582	**1,000**
M_EFF SCORES	**0,783**	**0,956**	**0,729**	**0,754**	**0,683**	**0,967**

Table B3.5 The results of PEG formulation and M_EFF scores for the candidate distributors of the region of "İzmir"

TEST / TARGET	1	2	3	4	5	6	7	8	9	10	11
1	**0,379**	0,516	0,400	0,715	0,433	0,423	0,870	0,864	0,643	0,616	0,534
2	0,183	**0,517**	0,401	0,419	0,209	0,402	0,517	0,595	0,596	0,298	0,393
3	0,165	0,465	**0,494**	0,376	0,188	0,400	0,553	0,535	0,536	0,268	0,353
4	0,218	0,517	0,401	**0,716**	0,358	0,424	0,568	0,866	0,644	0,509	0,535
5	0,193	0,505	0,430	0,636	**0,534**	0,392	0,505	0,826	0,628	0,758	0,494
6	0,175	0,493	0,401	0,399	0,200	**0,424**	0,546	0,567	0,568	0,284	0,374
7	0,174	0,492	0,401	0,399	0,199	0,424	**0,872**	0,567	0,567	0,283	0,374
8	0,203	0,517	0,401	0,609	0,305	0,411	0,530	**0,866**	0,644	0,433	0,518
9	0,198	0,517	0,401	0,453	0,226	0,402	0,518	0,643	**0,644**	0,322	0,424
10	0,209	0,517	0,401	0,688	0,498	0,424	0,546	0,866	0,643	**0,820**	0,534
11	0,209	0,517	0,401	0,570	0,285	0,424	0,546	0,810	0,643	0,405	**0,534**
12	0,379	0,517	0,401	0,716	0,498	0,424	0,871	0,866	0,643	0,767	0,534
13	0,168	0,475	0,401	0,385	0,192	0,402	0,518	0,547	0,548	0,274	0,361
14	0,165	0,464	0,428	0,376	0,188	0,400	0,545	0,535	0,535	0,267	0,353
15	0,165	0,465	0,401	0,376	0,188	0,392	0,505	0,535	0,536	0,268	0,353
16	0,193	0,517	0,401	0,442	0,221	0,424	0,546	0,628	0,629	0,314	0,414
17	0,165	0,464	0,443	0,376	0,188	0,400	0,596	0,535	0,535	0,267	0,353
18	0,203	0,517	0,401	0,667	0,431	0,411	0,529	0,866	0,644	0,612	0,518
19	0,201	0,517	0,401	0,459	0,229	0,424	0,622	0,652	0,644	0,326	0,430
20	0,203	0,517	0,401	0,667	0,411	0,411	0,530	0,866	0,644	0,584	0,518
21	0,193	0,505	0,435	0,496	0,248	0,392	0,505	0,705	0,628	0,352	0,465
22	0,219	0,517	0,401	0,577	0,289	0,424	0,572	0,820	0,644	0,410	0,535
M_EFF SCORES	**0,207**	**0,502**	**0,411**	**0,523**	**0,296**	**0,412**	**0,587**	**0,707**	**0,608**	**0,429**	**0,450**

Table B3.5 (Cont'd)

TEST / TARGET	12	13	14	15	16	17	18	19	20	21	22
1	0,559	0,835	0,484	0,998	0,630	0,441	0,551	0,557	0,630	0,580	0,522
2	0,270	0,836	0,485	0,999	0,597	0,424	0,268	0,463	0,322	0,532	0,380
3	0,243	0,819	0,518	1,000	0,538	0,453	0,241	0,458	0,289	0,478	0,341
4	0,371	0,837	0,485	1,000	0,631	0,442	0,459	0,510	0,550	0,581	0,520
5	0,329	0,816	0,479	0,999	0,583	0,414	0,526	0,453	0,602	0,623	0,462
6	0,258	0,836	0,485	0,999	0,570	0,441	0,256	0,486	0,306	0,507	0,362
7	0,257	0,837	0,485	1,000	0,569	0,442	0,255	0,485	0,306	0,507	0,361
8	0,346	0,837	0,485	1,000	0,612	0,434	0,390	0,475	0,468	0,581	0,484
9	0,292	0,837	0,485	1,000	0,598	0,424	0,290	0,464	0,347	0,575	0,410
10	0,356	0,836	0,485	0,999	0,631	0,441	0,552	0,489	0,631	0,581	0,500
11	0,356	0,836	0,484	0,998	0,630	0,441	0,365	0,489	0,437	0,580	0,499
12	**0,697**	0,836	0,485	0,999	0,631	0,441	0,552	0,558	0,631	0,581	0,523
13	0,249	**0,837**	0,485	1,000	0,550	0,424	0,247	0,464	0,295	0,489	0,349
14	0,243	0,818	**0,517**	0,999	0,537	0,447	0,241	0,457	0,289	0,478	0,341
15	0,243	0,817	0,479	**1,000**	0,538	0,414	0,241	0,453	0,289	0,478	0,341
16	0,285	0,837	0,485	1,000	**0,631**	0,442	0,283	0,490	0,339	0,561	0,400
17	0,243	0,818	0,517	1,000	0,538	**0,488**	0,241	0,458	0,289	0,478	0,341
18	0,345	0,837	0,485	0,999	0,612	0,434	**0,552**	0,475	0,631	0,581	0,484
19	0,296	0,837	0,485	1,000	0,631	0,442	0,294	**0,558**	0,352	0,581	0,416
20	0,346	0,837	0,485	1,000	0,612	0,434	0,526	0,475	**0,631**	0,581	0,485
21	0,320	0,816	0,479	0,999	0,583	0,413	0,318	0,452	0,381	**0,630**	0,449
22	0,373	0,837	0,485	1,000	0,631	0,442	0,370	0,512	0,443	0,581	**0,523**
M_EFF SCORES	**0,331**	**0,831**	**0,488**	**0,999**	**0,595**	**0,437**	**0,364**	**0,485**	**0,430**	**0,552**	**0,431**

APPENDIX B4
DATA ON LOCATION AND DEMAND FOR THE CANDIDATE DISTRIBUTORS

Table B4.1 Location and demand data for the candidate distributors of "Adana"

DISTRIBUTORS	LOC	DEM
1	78	1692
2	78	1705
3	78	1606
4	74	1418
5	76	1609
6	74	1349
7	78	1368
8	78	1706
9	80	1658
10	79	1525

Table B4.2 Location and demand data for the candidate distributors of "Diyarbakır"

DISTRIBUTORS	LOC	DEM
1	71	603
2	67	659
3	66	445
4	62	622
5	57	642
6	71	610
7	69	552

Table B4.3 Location and demand data for the candidate distributors of "İstanbul"

DISTRIBUTORS	LOC	DEM
1	87	4864
2	91	5316
3	91	5000
4	87	5688
5	87	5446
6	87	4583
7	87	4565
8	87	2966
9	86	4413
10	86	5045

Table B4.4 Location and demand data for the candidate distributors of "İzmir"

DISTRIBUTORS	LOC	DEM
1	89	2316
2	88	3408
3	89	3132
4	89	2364
5	97	2772
6	95	2976
7	95	3096
8	100	3492
9	93	3144
10	92	2436
11	94	2148
12	100	1752
13	100	3420
14	99	3036
15	89	3120
16	100	3300
17	100	3072
18	92	3252
19	93	2832
20	96	3204
21	93	2880
22	95	2952

Table B4.5 Location and demand data for the candidate distributors of "Samsun"

DISTRIBUTORS	LOC	DEM
1	64	1004
2	74	1094
3	67	1109
4	74	894
5	80	1125
6	75	1103