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The Graduate School of Sciences and Engineering

Master of Science in
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A Case Study on Reverse Supply Chain by using Goal Programming

by

Muhammad Umar Farooq

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APPROVAL PAGE

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ABSTRACT

In this thesis, main focus is on supply chain network design with a concern to minimize the rejection and maximize the customer satisfaction by fulfilling demand. In supply chain there are many stake holders; suppliers, manufacturers, distribution centers and retailers, customers and many others. Strategic decisions on establishing a supply chain network (SCN) encompass more than one criterion. For example, a conventional criterion for supply chain is cost optimization. But there can be many other criteria. For example customer service levels, environmental and quality issues, supplier selection, solid waste management, etc. These objectives are usually incompatible, as they usually involve trade-offs. As the number of criteria increases, there will be no effect on the theoretical domain of the problem but the formulation and computation time will increase. Additionally the complexity of the problem will also increase. So to make the situation clear and easier, three objectives (criteria) will be chosen such as; i) conventional supply chain objective – profit maximization, ii) minimizing the rejection and iii) maximizing the demand fulfillment.

If there is any part which can be recycled then it should be used as much as possible because it will not only reduce the total cost of the supply chain but also it will reduce environmental issues. In the end it is also a cost minimizing element. These objectives will be analyzed along with constraints such as demand, supply, operational capacity, holding capacity and rejection constraints of a particular product by means of optimization software like AMPL. In this research, estimated demand from various retail units, capacity commitment by the suppliers, assemblers and ware houses have been considered as constraints in order to develop a multiple-objective decision – making model for the choice of warehouses and recyclable amount for a supply chain network (SCN) design. The SCN is considered for the production of multiple products.It will be shown that compared to the optimal solution generated by

considering only one objective differs when two objectives are considered simultaneously.

Key Words: Stakeholders, Recyclable material, supply chain network, demand fulfillment, customer service level, quality issues, multiple-objective decision making

Hedef Programlama ile Tersine Tedarik Zinciri Üzerine Bir Çalışma

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ÖZ

Bu tezde, tedarik zinciri ağı tasarımı ile talepleri karşılarken müşteri memnuniyetsizliğini en aza indirmeye ve memnuniyeti maksimum seviyelere ulaştırmaya odaklandım.Tedarikçiler, üreticiler, dağıtım merkezleri ve perakendeciler, müşteriler gibi tedarik zincirinde birçok paydaşlar vardır.Bir tedarik zinciri ağının kurulması aşamasında alınacak stratejik kararlar birden fazla ölçütü içerir.Örneğin, tedarik zinciri için sıkça kullanılan bir kriter maliyet optimizasyonudur fakat diğer birçok kriter de kullanılabilir.Örneğin müşteri hizmet düzeyleri, çevre ve kalite sorunları, tedarikçi seçimi, katı atık yönetimi gibi. Genellikle bu kriterler birbirleriyle uyumsuzluk gösterirler ve aralarında bir trade-off vardır. Kriter sayısının artması problemin teorik etki alanına bir etkisi olmayacaktır ve çözüm için daha fazla zaman harcanacaktır. Buna ek olarak, sorunun karmaşıklığını da artıracaktır.Bundan dolayı problemi daha basit bir çözüme ulaştıracak şekilde 3 ana kriter seçilecektir; i) geleneksel tedarik zinciri, maliyet minimizasyonu,ii) memnuniyetsizliği en aza indirmek and iii) talepleri karşılamada en üst düzeye ulaşmak.

Zincirde eğer bir bölüm geridönüştürülebilir ise bu kısım mümkün olduğunca tekrardan kullanımalıdır çünkü bu bölüm zincirin sadece maliyetini düşürmeyecek aynı zamanda çevre sorunlarını da azaltacaktır. Sonuç olarak bu bölüm maliyeti indirme elementidir. Bu hedefler, arz, talep, operasyonel kapasite, stok kapasitesi ve ıskartaya çıkartma kısıtları altında AMPL programı ile analiz edilecektir.Bu araştırmada, çeşitli perakende birimlerinde ki tahmini talepler, tedarikçi, montaj ve depolardaki kapasite sınırları kısıt olarak kabul edilerek depo seçimi ve geri dönüştürülebilir birimler için tedarik zincirinde çok amaçlı karar verme modeli geliştirilmiştir.Tedarik zinciri ağı birden fazla ürün üretimi için kabul edilir.İki amaç aynı anda dikkate alındığında ;

sadece bir amacın dikkate alınmasının optimum sonuçtan farklı değerler ortaya koyduğu gözlemlenecektir. Bu iki amacı aynı anda dikkate alındığında tek bir amacı farklıdır dikkate alınarak oluşturulan en iyi çözüm ile karşılaştırıldığında gösterilecektir..

Anahtar Kelimeler: Paydaşlar, Geri dönüştürülebilir malzeme, tedarik zinciri ağ, talep yerine getirilmesi, müşteri hizmet düzeyi, kalite sorunları, yapım çok amaçlı karar.

To my beloved country- Pakistan

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Words are bound and knowledge is limited to praise Allah Almighty, the Lords of words, the most the beneficent, the compassionate, and the merciful. Person is not perfect in all context of this life, he has a limited mind and thinking approaches. It is the guidance from the Almighty Allah that shows the man, light in the darkness and the person finds his way in that light. Without this helping light, person is nothing, but a helpless creature.

It has finished and now I can take a deep breath, really deep! I have gained great experience from this thesis work in terms of knowledge I acquired, new people I met, and institutions I visited. Therefore I will always remember this process mostly with nice memories.

It is humbling to think of the number of people without whom this work would be nothing at all. I have had more excellent teachers than even extreme good fortune should allow and I am grateful to all of them. I am highly indebted to Assistant Professor Dr. Özlem COŞGUN for the faith she bestowed upon me with this thesis, for being my mentor throughout my stint at Fatih University.

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SYMBOL/ABBREVIATION

SC : Supply Chain
SCM : Supply Chain Management
RSC : Reverse Supply Chain
RSCM : Reverse Supply Chain Management
MODM : Multi Objective Decision Making
DM : Decision Making
DC : Distribution Centers
AMPL : A Mathematical Programming Language
SCN : Supply Chain Network
GP : Goal Programming
LP : Linear Programming
EDI : Electronic Data Interchange

CHAPTER 1

INTRODUCTION

In this thesis, it was focused on enhancing the effectiveness of the supply chain management by means of goal programming. For years, researchers and practitioners have primarily investigated the various processes within manufacturing supply chains individually. Recently, however, there has been increasing attention placed on the performance, design, and analysis of the supply chain as a whole. This attention is largely a result of the rising costs of manufacturing, the shrinking resources of manufacturing bases, shortened product life cycles, the leveling of the playing field within manufacturing, and the globalization of market economies. [1]

1.1 THE SUPPLY CHAIN EVOLUTION

As recently as the early 1990s, the average time required for a company to process and deliver merchandise to a customer from warehouse inventory ranged from 15 to 30 days, sometimes even longer. The typical order-to-delivery scenario involved order creation and transfer, which was usually via telephone, fax, electronic data interchange (EDI), or public mail; followed by order processing, which involved the use of manual or computer systems, credit authorization, and order assignment to a warehouse for selection; followed by shipment to a customer. When everything went as planned, the average time for a customer to receive items ordered was lengthy. When something went wrong (as it most often did), such as inventory out-of-stock a lost or misplaced work order, or a misdirected shipment, total time to service customers escalated rapidly.To support this lengthy and unpredictable time to market, it became common practice to stockpile inventory. For example, inventories of identical products were typically stocked by retailers, wholesalers, and manufacturers. Despite such extensive inventory, out-of-stocks and delayed deliveries remained pervasive due to large number of product variations.

These accepted business practices of the 20th century, as well as the distribution channel structure used to complete delivery, evolved from years of experience that dated from industrial revolution. Such long-standing business practices remained in place and unchallenged because no clearly superior alternative existed. The traditional distribution process was designed to overcome challenges and achieve benefits that long ago ceased to be important. The industrialized world is no longer characterized by scarcity. Consumer affluence and desire for wide choice of products and services continues to accelerate. In fact, today's consumers want a wide range of options they can configure to their unique specifications. The desires of customers have shifted from passive acceptance to active involvement in the design and delivery of specific products and services. Transportation capacity and operational performance has increasingly become more economical and reliable, as today's transportation is supported by sophisticated technology that facilitates predictable and precise delivery.

Most of all, a massive change has occurred as a result of of information availability. During the decade of 1990s, the world of commerce was irrevocably impacted by computerization, the internet, and a range of inexpensive information transmission capabilities. Information characterized by speed, accessibility, accuracy, and most of all relevancy became the norm. The internet, operating at Web speed, has become an economical way to conduct transactions and launched the potential of business-to-business (B2B) consumer direct e-distribution. Driven by these fundamental forces, a global economy rapidly emerged.

What began during the last decade of the 20th century and will continue to unfold well into the 21st century is what historians will characterize as the dawning of the information or digital age. In the age of electronic commerce, the reality of B2B connectivity has made possible a a new order of business relationships called supply chain management. Managers are increasingly questioning traditional distribution, manufacturing, and purchasing practices. In this new order of affairs, products can be manufactured to exact specifications and rapidly delivered to customers at locations throughout the globe. Logistical systems exist that have the capability to deliver products at exact times. Customer's orders and delivery of a product can be performed in hours. The frequent occurrence of service failures that characterized the past is increasingly being replaced by a growing managerial commitment to zero defect.

1.2 THE SUPPLY CHAIN REVOLUTION

What managers are experiencing today we choose to describe as supply chain revolution and related logistical renaissance. These two massive shifts in expectation and practice concerning the performance of business operations are highly interrelated but they are significantly different aspects of contemporary strategic thinking.

Supply chain (sometimes called the value chain or demand chain) management consists of firms collaborating to leverage strategic positioning and to improve operating efficiency. For each firm involved, the supply chain relationship reflects strategic choice. A supply chain strategy is a channel arrangement based on acknowledged dependency and relationship management. Supply chain operations require managerial processes that span across functional areas within individual firms and link trading partners and customers across organizational boundaries.

Logistics in contrast to supply chain management, is the work required to move and position inventory throughout a supply chain. Such a logistics is a subset of and occurs within the broader framework of supply chain. Logistics is the process that creates value by timing and positioning inventory; it is the combination of a firm's order management, inventory, transportation, warehousing, material handling, and packaging as integrated throughout a facility network. Integrated logistics serves to link and synchronize the overall supply chain as a continuous process and is essential for effective supply chain connectivity. While the purpose of logistical work has remained essentially the same over the decades, the way the work is performed continues to radically change.

1.3 Generalized Supply Chain Model

The general concept of an integrated supply chain is typically illustrated by a line diagram that links participating firms into a coordinated competitive unit. Following figure illustrates a generalized model adapted from the supply chain management program at Michigan State University.

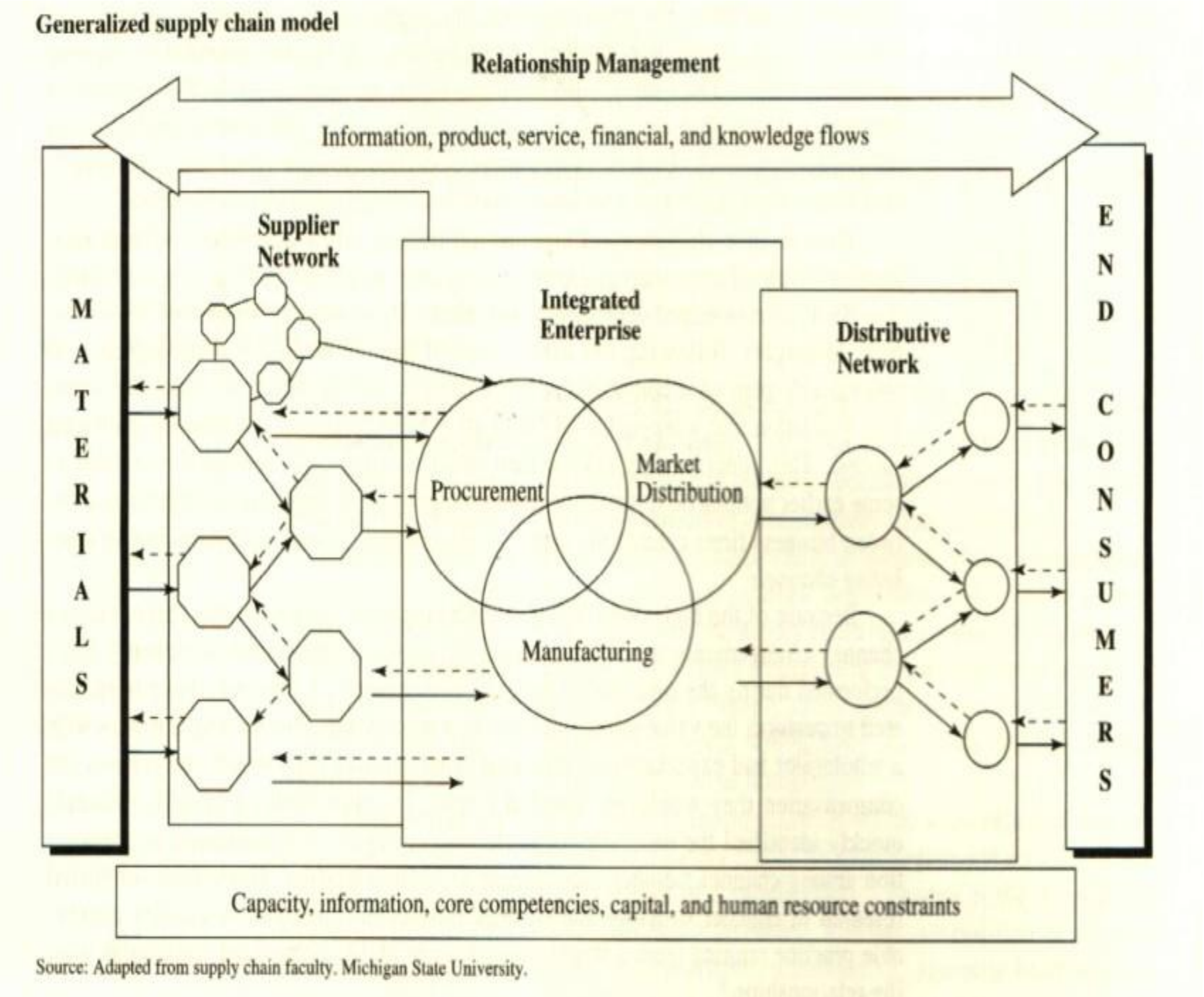

Figure 1.1 Supply chain model

The generalized supply chain arrangement illustrated in above figure logically and logistically links a firm and its distributive and supplier network to end customers. The message conveyed in this figure is that the integrated value-creation process must be managed from material procurement to end-customer product/service delivery.

A supply chain is basically a group of independent organizations connected together through the products and services that they separately and/or jointly add value on in order to deliver them to the end consumer. It is very much an extended concept of an organization which adds value to its products or services and delivers them to its customers.

Over the last three decades, the concept and theory of business management have undergone profound changes and development. Many old ways of doing business have been challenged and many new ideas and approaches have been created, among them are business process re-engineering, strategic management, lean thinking, agile manufacturing, balanced scorecard, blue ocean strategy,… just to name a few. Supply chain is undoubtedly one of those new and well grown management approaches emerged and rapidly developed across all industries around the world.

The earliest appearance of the term ‘supply chain’ as we know it today published in recognizable media and literatures can be traced back to early 1980s. More precisely, it first appeared in a Financial Times article written by Oliver and Webber in 1982 describing the range of activities performed by the organization in procuring and managing supplies. However the early publications of supply chain are the 1980s were mainly focused on purchasing activities and cost reduction related activities. The major development and significant increases of publications in the areas of supply chain integration and supplier-buyer relationship came in 1990s when the concept as we know it today was gradually established.

It is therefore clear that supply chain is not one of the legacy academic subjects existed for hundreds or thousands of years, but rather a young and even nascent subject. It is only recently that business world started making use of this concept. So the question is ‘Why now?’ A convincing answer to this question is that our business environment has changed, which includes globalization, more severe competition, heightened customer expectation, technological impact and geopolitical factors and so on. Under such a renewed business environment, an organization focused management approach is no longer adequate to deliver the required competitiveness. Managers must therefore understand that their businesses are only part of the supply chains that they participated and it is supply chain that winds or loses the competition.

Thus the arena of competition is moving from ‘organization against organization’ to ‘supply chain against supply chain’. The survival of any business today is no longer solely dependent on its own ability to compete but rather on the ability to cooperate within the supply chain. The seemingly independent relation between the organizations within the supply chain becomes even more interdependent. You “sink or swim with the supply chain”. It is for this reason that gives rise to the need for supply chain management and optimization.

Supply chain management is also pervasive and ubiquitous. One can hardly find any aspect of business that has nothing to do with supply chain management. Take an example of quality management – a very important part of today’s business management, and ask yourself a question: can you manage and improve the quality standard of your product or service measured by the end-consumer without managing the suppliers and buyers in the supply chain at all? of course not. Business value creation is always a collective contribution from the whole involved supply chain. On the basis of above discussion supply chain can be defined as; a group of inter-connected participating companies that add value to a stream of transformed inputs from their source of origin to the end products or services that are demanded by the designated end-consumers.

The supply chain planning in reverse logistics for end-of-life (EOL) products embraces many different characteristics of environmentally conscious manufacturing, including disassembly, reuse, recycling, and remanufacturing. As manufacturers change from isolated business units to integrated network partners, they require effective and efficient Supply Chain Planning (SCP) strategies for materials, components, and products. SCP can help speed up the reverse logistics through the availability of online marketplace to support the networking of environmentally conscious product suppliers, manufacturers, distributors and customers.

1.4 CRITICAL DELIVERABLES OF SC

What we want to achieve, by optimizing a supply chain by applying any methodology whether it is goal programming or integer programming, are improvements in some functional areas. For example we want to decide the location of an outlet in such a way that it will not cause cannibalization. It means that it will not lower the sales of nearby outlets of the same company. Then this location planning is a critical deliverable of the supply chain optimization. These deliverables are usually in terms of monetary terms in the long run. For example, if SC is optimized, it can help in improving the layout which is a qualitative deliverable of SC. But this qualitative measure is helping in minimizing the total cost. Some of the critical deliverables of SC optimization (these are also for the reverse supply chain) are as follows;

- Location & Capacity
- Type of plants layout, warehouses, and distribution centers
- Distribution channels
- Amount of materials and items to consume, produce, and ship from suppliers to customers

1.5 PERFORMANCE MEASURES OF SC

Performance measures help us to analyze whether we got any improvement of not. It is actually the benefit measure of our methodology. If values of these performance measures are up to the mark, then is a validation of our methodology. These performance measures are of two types.

1.5.1 Qualitative

These performance measures involve no numerical data. But the principle of these performance measures is that qualitative data of these performance measures is first converted into quantitative data and then solved by using any methodology. For example, customer satisfaction is a qualitative measure. To measure customer satisfaction, we need to gather data which describes customer satisfaction. i.e. repeat orders describe customer satisfaction. If a customer makes purchases several times from a company, then it literally means that that customer is satisfied from the company. Followings are some of the qualitative measures which I found in literature;

- Customer satisfaction

- Flexibility
- Effective risk management

1.5.2 Quantitative

These measures may also be termed as conventional measures because these involve numerical data for the analysis of supply chain performance. Some of the mostly used quantitative performance measures are as follows;

- Economic Objectives i.e. cost minimization, sales maximization, profit maximization, etc.
- Objectives bases on customer responsiveness i.e. fill rate maximization, customer response time minimization, lead time minimization, etc.

CHAPTER 2

THEORETICAL BACK GROUND

Supply chain management (SCM) has received tremendous attention both from the business world and from academic researchers during the last 15 years. SCM can be defined as “a set of approaches utilized to efficiently integrate suppliers, manufacturers, 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”[2].

Most of the SCM research concentrates on the forward movement and transformation of the materials from the suppliers to the end consumer and on the impact that information has on the bullwhip effect as it transverses upstream. However, the reverse flow of products from consumers to upstream businesses has not received much interest. [3, 4]

The management of the reverse flows is an extension of the traditional supply chains with used product or material either returning to reprocessing organizations or being discarded. Reverse supply chain management (RSCM) is defined as the effective and efficient management of the series of activities required to retrieve a product from a customer and either dispose of it or recover value [5]. The importance of studying reverse supply chains (RSCs) has increased in recent years for several reasons.

- The amount of product returns can be very high, with some industries experiencing returns at over 50% of sales [6].
- Sales opportunities in secondary and global markets have increased revenue generation from previously discarded products [7].
- End-of-life take-back laws have proliferated over the past decade both in the European Union and in the United States, requiring businesses to effectively manage the entire life of the product [8, 9].

- Consumers have successfully pressured businesses to take responsibility for the disposal of their products that contain hazardous waste [10].
- Landfill capacity has become limited and expensive. Alternatives such as repackaging, remanufacturing and recycling have become more prevalent and viable [11, 12].

Although the use of RSCM activities is increasing, business managers struggle with how to better manage their time and resources with these sometimes “pesky” activities. Managers view several impediments to successful RSCM:

- Delayed returns, which are especially important for technological and time-sensitive products;
- Variation in quantity of product returns;
- Severity and breadth of product defects and
- Unknown product quality since information at the consumer or retail level is typically not communicated through the RSCs.

Companies that overcome these challenges expect to see improved revenue generation and reduced costs associated with product returns [6, 13].

The studies on RSCM have relied predominantly on normative research methods (see Fleischmann et al. [14] for a review), case studies (see de Brito et al. [15] for a review) or theoretical frameworks (e.g., [16, 17, 18]). Although there are a few studies that have relied on survey-based empirical methods, most have provided only descriptive statistics [19, 20].

Rupesh Kumar Pati , Prem Vrat and Pradeep Kumar proposed a multi-objective model for economic optimization and environment protection in a paper industry. The output of the model was reduction in reverse logistic cost, product quality improvement through increased segregation at the source and the environmental benefits through increased wastepaper recovery. The proposed model was also helpful in determination of facility location, route and flow of different varieties of recyclable waste paper [21].

Bijay Baran Pal and Bhola Nath Moitra proposed an approach to find the most satisfactory solution for a GP model. In the approach proposed by them, first of all an aspiration level for different goals are described and then highest priority goal is solved first. The solution of this phase is used as constraint in the next phase. This process is repeated until all the goals are satisfied up to their aspiration levels [22].

Yannis A. Hajidimitriou, Andreas C.Georgiou proposed a model for selection of partners in international joint ventures. They proposed the first quantitative model for this purpose which is a multi objective model based on goal programming techniques. The concerns for selecting a partner are quantitative and qualitative which reflect the strategic objectives of the firm and the goals associated with these criteria as well as their rankings [23].

U.K. Bhattacharya proposed a model for advertisement problem by using chance constraint goal programming. His model helps in deciding the number of advertisements in different advertising media and optimal allocation of budget assigned to different media. The main concern of the model was to maximize the reach of advertisement to desired section of people within maximum allowable budget without violating the maximum and minimum number of advertisement goals [24].

Shaligram Pokharel described in his research that supply chain network design of any organization encompasses more than one criterion. The criteria he used in his research were minimization of cost and maximization of customer level. He analyzed these criteria considering some constraints like estimated demand for various retail units, capacity commitments by various suppliers for the production of a particular product and third party warehouses [25]

Benita M. Beamon conducted a research for supply chain models and methods to analyze those models. According to his research, there are basically four types of models;

- Economic models,
- Simulation models,
- Stochastic Models,
- Deterministic Models

Every researcher makes a model which is one of the above mentioned models. To analyze the model, different performance measures are selected. And to achieve that performance, different variables are played with. For example, when we are considering any manufacturing industry and we want to reduce the cost then it can be achieved by many variables. One important variable for this purpose is inventory level. How much we should maintain the inventory in order to minimize the cost [4].

Alitok and R. Rajnan presented a stochastic model as it involved some element of probability. In their model, they determined how cost can be reduced and customer responsiveness can be increased by controlling the decision variables like inventory levels, ordering batch sizes and number of stages involved in the supply chain. [26]

Arntzen, Bowen and Harrison proposed a model for global supply chain management which was deterministic in nature. In their research, they found out how to reduce the cost and the activity time by playing with variables like production/ distribution scheduling, inventory levels, ordering batch sizing, location of distribution center, assignment of customers to the distribution centers and plant assignment for a specific product [27].

In their research, J.D. Camm, T.E. Chorman, F.A. Dull, J.R. Evans, D.J. Sweeney and G.W. Wegryn resulted that cost and activity time can be minimized by having effective control on buyer-supplier relationship, location of distribution center and allocation of customers to distribution centers. The model proposed by them was deterministic as described by Benita M. Beamon’s four models [28].

Christy and Grout analyzed an economical model on basis of cost, customer responsiveness and back orders. They checked the effects of production and distribution scheduling, and product differentiation step application. Their study opened new research horizons for product differentiation field as it involved research and development focus [29].

Cohen and Lee while working on stochastic model proposed that cost and flexibility are dependent are on inventory levels, ordering batch sizes, production scheduling and distribution scheduling [30].

Cohen and Lee in their research worked on deterministic model. In this model, they minimized the cost and maximized the flexibility performance measures by controlling inventory levels, ordering bath sizes, production scheduling and distribution scheduling [31].

Cohen and Moon who worked on deterministic model concluded that cost can be reduced by proper scheduling of production and distribution.[32].Roghanian, Sadjadi worked on stochastic model. In his model, basic emphasis was on cost reduction by means of production and distribution scheduling, inventory levels and ordering batch sizes [33].

Ishii et al. proposed on deterministic model. He selected cost and customer responsiveness as performance measures. To achieve those performance measures, he used production and distribution scheduling and inventory levels [34].

Lee and Billington developed a heuristic stochastic model for managing materials flows on a site-by-site basis. Specifically, they modeled a pull type, periodic, order up to inventory system and determined the review period and order up to quantity as model outputs. They developed a model which either determines the material ordering policy by calculating the required stock levels to achieve a given target service level for each product at each facility or determine the service level for each product at each facility, given a material ordering policy [35].

Lee and Feitzinger develop an analytical model to analyze product configuration for post- ponement (i.e., determining the optimal production step for product differentiation), assuming stochastic product demands. The authors assume a manufacturing process with I production steps that may be performed at a factory or at one of the M distribution centers (DCs). The problem is to determine a step P such that steps 1 through P will be performed at the factory and steps (P#1) to I will be performed at the DCs. The authors solve this problem by calculating an expected cost for the various product configurations, as a sum of inventory, freight, customs, setup, and processing costs. The optimal value of P is the one that minimizes the sum of these costs [36].

Lee et al. developed stochastic mathematical models describing "The Bullwhip Effect", which is defined as the phenomenon in which the variance of buyer demand becomes increasingly amplified and distorted at each echelon upwards throughout the supply chain. That is, the actual variance and magnitude of the orders at each echelon is increasingly higher than the variance and magnitude of the sales, and this phenomenon propagates upstream within the chain. In this research, the authors developed stochastic analytical models describing the four causes of the bullwhip effect (demand signal processing, rationing game, order batching, and price variations), and showed how these causes contribute to the effect [37].

Lee et al.developed a stochastic, periodic review, order-up-to inventory model to develop a procedure for process localization in the supply chain. That is, the authors proposed an approach to operational and delivery processes that consider differences in target market structures (e.g., differences in language, environment, or governments). Thus, the objective of this research was to design the product and production processes that are suitable for different market segments that result in the lowest cost and highest customer service levels [38].

Pyke and Cohen develop a mathematical programming model for an integrated supply chain, using stochastic sub-models to calculate the values of the included random variables included in the mathematical program. The authors considera three level supply chain, consisting of one product, one manufacturing facility, one warehousing facility, and one retailer. The model minimizes total cost, subject to a service level constraint, and holds the setup times, processing times, and replenishment lead times constant. The model yields the approximate economic (minimum cost) reorder interval, replenishment batch sizes, and the order-up to product levels (for the retailer) for a particular production network [39].

Pyke and Cohen followed the Pyke and Cohen [39] research by including a more complicated production network. In Pyke and Cohen, the authors again considered an integrated supply chain with one manufacturing facility, one warehouse and one retailer, but now considered multiple product types. The new model yielded similar outputs; however, it determined the key decision variables for each product type. More specifically, this model yielded the approximate economic (minimum cost) reorder interval (for each product type), replenishment batch sizes (for each product type), and the order-up-to product levels (for the retailer, for each product type) for a particular supply chain network [40].

Newhart et al. designed an optimal supply chain using a two-phase approach. The first phase was a combination mathematical program and heuristic model, with the objective of minimizing the number of distinct product types held in inventory throughout the supply chain. This was accomplished by consolidating substitutable product types into single SKUs. The second phase was a spreadsheet-based inventory model, which determined the minimum amount of safety stock required to absorb demand and lead time fluctuations. The authors considered four facility location alternatives for the placement of the various facilities within the supply chain. The next step was to calculate the amount of inventory investment under each alternative, given a set of demand requirements, and then select the minimum cost alternative [41].

Svoronos and Zipkin consider multi-echelon, distribution-type supply chain systems (i.e.,each facility has at most one direct predecessor, but any number of direct successors). In this research, the authors assume a base stock, one-for-one (S!1, S) replenishment policy for each facility, and that demands for each facility follow an independent Poisson process. The authors obtain steadystate approximations for the average inventory level and average number of outstanding backorders at each location for any choice of base stock level. Finally, using these approximations, the authors propose the construction of an optimization model that determines the minimum-cost base stock level [42].

Towill and Towill et al. use simulation techniques to evaluate the effects of various supply chain strategies on demand amplification. The strategies investigated are as follows:

1. Eliminating the distribution echelon of the supply chain, by including the distribution function in the manufacturing echelon.
2. Integrating the flow of information throughout the chain.
3. Implementing a just-in-time (JIT) inventory policy to reduce time delays.
4. Improving the movement of intermediate products and materials by modifying the order quantity procedures.
5. Modifying the parameters of the existing order quantity procedures.

The objective of the simulation model is to determine which strategies are the most effective in smoothing the variations in the demand pattern. The just-in-time strategy (strategy 3 above) and the echelon removal strategy (strategy 1 above) were observed to be the most effective in smoothingdemand variations [43, 44].

Towill and Del Vecchio [23] consider the application of filter theory and simulation to the study of supply chains. In their research, the authors compare filter characteristics of supply chains to analyze various supply chain responses to randomness in the demand pattern. These responses are then compared using simulation, in order to specify the minimum safety stock requirements that achieve a particular desired service level. [45]

Tzafestas and Kapsiotis utilize a deterministic mathematical programming approach to optimize a supply chain, and then use simulation techniques to analyze a numerical example of their optimization model. In this work, the authors perform the optimization under three different scenarios:

1. Manufacturing facility optimization: Under this scenario, the objective is to minimize the total cost incurred by the manufacturing facility only; the costs experienced by other facilities is ignored.
2. Global supply chain optimization: This scenario assumes a cooperative relationship among all stages of the supply chain, and therefore minimizes the total operational costs of the chain as a whole.
3. Decentralized optimization: This scenario optimizes each of the supply chain components individually, and thus minimizes the cost experienced by each level. The authors observe that for their chosen example, the differences in total costs among the three scenarios do not differ significantly [46].

Voudouris develops a mathematical model designed to improve efficiency and responsiveness in a supply chain. The model maximizes system flexibility, as measured by the time-based sum of instantaneous differences between the capacities and utilizations of two types of resources: inventory resources and activity resources. Inventory resources are resources directly associated with the amount of inventory held; activity resources, then are resources that are required to maintain materialflow. The model requires, as input, product-based resource consumption data and bill-of-material information, and generates, as output: (1) a production, shipping, and delivery schedule for each product and (2) target inventory levels for each product.[47]

Williams presents seven heuristic algorithms for scheduling production and distribution operations in an assembly supply chain network (i.e. each station has at most one immediate successor, but any number of immediate predecessors). The objective of each heuristic is to determine a minimum-cost production and/or product distribution schedule that satisfies the final product demand. The total cost is a sum of the average inventory holding and fixed (ordering, delivery, or setup) costs. Finally, the performance of each heuristic is compared using a wide range of empirical experiments, and recommendations are made on the bases of solution quality and network structure [48].

Williams develops a dynamic programming algorithm for simultaneously determining the production and distribution batch sizes at each node within a supply chain network. As in Williams, it is assumed that the production process is an assembly process. The objective of the heuristic is to minimize the average cost per period over an infinite horizon, where the average cost is a function of processing costs and inventory holding costs for each node in the network. [49]

Wikner et al. examine five supply chain improvement strategies, and then implement these strategies on a three-stage reference supply chain model. The five strategies are:

1. Fine-tuning the existing decision rules.
2. Reducing time delays at and within each stage of the supply chain.
3. Eliminating the distribution stage from the supply chain.
4. Improving the decision rules at each stage of the supply chain.
5. Integrating the flow of information, and separating demands into “real” orders, which are true market demands, and “cover” orders, which are orders that bolster safety stocks. Their reference model includes a single factory (with an on-site warehouse), distribution facilities, and retailers. Thus, it is assumed that every facility within the chain houses some inventory. The implementation of each of the five different strategies is carried out using simulation, the results of which are then used to determine the effects of the various strategies on

minimizing demand fluctuations. The authors conclude that the most effective improvement strategy is strategy 5, improving the flow of information at all levels throughout the chain, and separating orders [50].

Table 2.1(Cont.) Literature summary

Authors	Model Types				Performance Measures				Decision Variables								
	Deterministic	Stochastic	Economic	Simulation	Cost	Customer Responsiveness / Back	Activity	Flexibility	Production / Distribution Scheduling	Inventory / Levels	No of Stages	DC customer assignment / Location	Plant / product	Buyer / Supplier	Product Differentiation Step	Number of Product types held in	No of Advertisement
Altiok and Ranjan		✓			✓	✓				✓	✓						
Arntzen et al.	✓				✓		✓		✓	✓		✓	✓				
Bhattach-arya	✓				✓				✓								✓
Camm et al.	✓				✓							✓		✓			
Christy and Grout			✓		✓	✓											
Cohen and Lee		✓			✓					✓							
Cohen and Lee	✓				✓				✓	✓							
Cohen and Moon	✓				✓				✓								
Roghanian, Sadjadi,		✓			✓				✓	✓							
Ishii et al.	✓				✓	✓			✓	✓							

Table 2.1 Literature summary

Billington																	
Lee and Feitzinger		✓			✓										✓		
Lee et al.		✓			✓	✓				✓							
Lee et al.		✓			✓												
Pyke and Cohen		✓			✓					✓							
Pyke and Cohen		✓			✓					✓							
Newhart et al.	✓				✓	✓				✓							
Svoronos and Zipkin		✓			✓	✓				✓						✓	
Towill				✓	✓					✓	✓						
Towill et al.				✓	✓	✓				✓	✓						
Towill and Del Vecchio	✓					✓				✓							
Tzafestas and Kapsiotis	✓				✓					✓							
Voudouris	✓							✓		✓							
Williams	✓				✓				✓								
Williams	✓				✓				✓								
Wikner et al.				✓	✓	✓			✓	✓	✓						

CHAPTER 3

REVERSE SUPPLY CHAIN & GOAL PROGRAMMING

Reverse supply chain management means environmentally conscious sustainable supply chain which is also called Green Supply Chain Management (GrSCM). GrSCM is defined as 'integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life'.

In early environmental management frameworks, operating managers were involved only at arm's length. Separate organizational units had responsibility for ensuring environmental excellence in product development, process design, operations, logistics, marketing, regulatory compliance and waste management. Today, this has changed. As in the quality revolution of the 1980s and the supply-chain revolution of the 1990s, it has become clear that the best practices call for integration of environmental management with ongoing operations.

Reverse supply-chain management is gaining increasing interest among researchers and practitioners of operations and supply chain management. The growing importance of reverse supply chain is driven mainly by the escalating deterioration of the environment, e.g. diminishing raw material resources, overflowing waste sites and increasing levels of pollution. However, it is not just about being environment friendly; it is about good business sense and higher profits. In fact, it is a business value driver and not a cost centre. In addition, the regulatory requirements and consumer pressures are driving reverse supply chain. Hence, the scope of reverse supply chain ranges from reactive monitoring of the general environment management programs to more proactive practices implemented through various Rs (Reduce, Re-use, Rework, Refurbish, Reclaim, Recycle, Remanufacture, Reverse logistics, etc.).The RSC process can be organized sequentially by five key steps: product acquisition, reverse logistics, inspection and disposition, reconditioning, and distribution and sales. [51]

Green operations relate to all aspects related to product manufacture/remanufacture, usage, handling, logistics and waste management once the design has been finalized. Green manufacturing aims to reduce the ecological burden by using appropriate material and technologies, while remanufacturing refers to an industrial process in which worn-out products are restored to like-new condition. Recycling, mainly driven by economic and regulatory factors, is performed to retrieve the material content of used and non-functioning products. Logistics represent up to 95% of total costs in recycling. Economically driven recycling finds its application in automobiles and the consumer electronics industry. Regulatory electronics recycling is also practiced.

3.1 REVERSE SUPPLY CHAIN MODEL

When material flows in forward direction; from manufacturing unit to end users, then it is forward supply chain as conventionally taken the meaning of supply chain. But when the product has reached its end of life stage then it moves back from end users to different stake holders of supply chain in a reverse direction. Because of this reverse direction flow, it is called reverse supply chain. In our case, this expired product comes to the manufacturer rather than any other stake holder of supply chain. Model of reverse supply chain RSC is as follows;

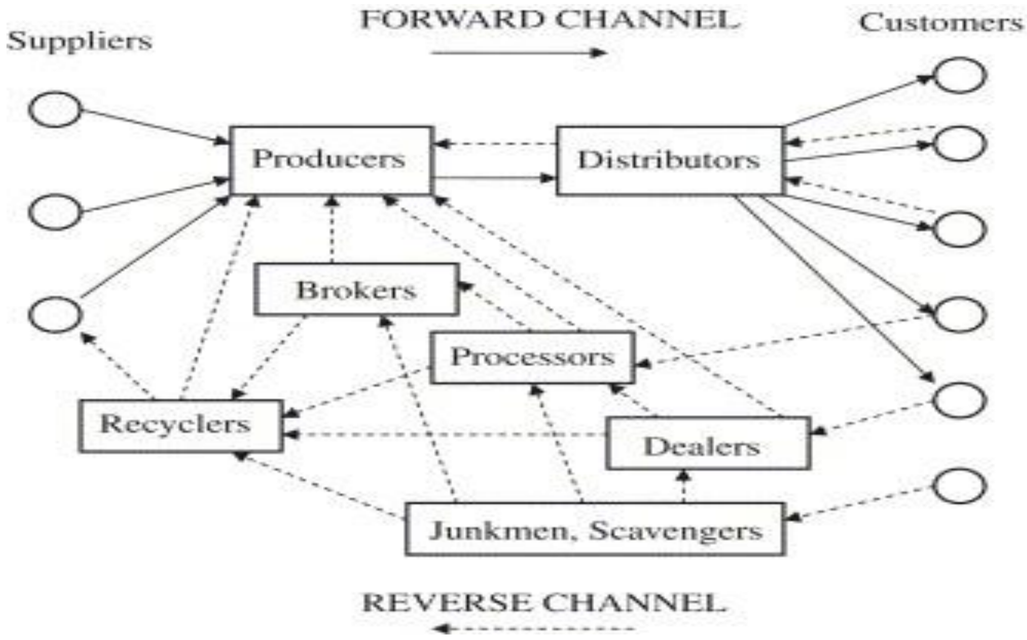

Figure 3.1 Reverse supply chain

Considerable efforts should be directed towards decreasing the environmental load by recycling. But multiple goals with appropriate priority structure must be taken into consideration when considering the recycling network system.

3.2 GOAL PROGRAMMING

A form of linear programming that allows for consideration of multiple goals. GP can be used to determine the optimal solution to a multi-objective decision problem which is a A form of decision analysis that seeks to analyze complex decision problems by dividing the problem into smaller understandable parts Then, we integrate the parts in a logical manner to produce a meaningful solution. The old saying that still holds in everyday life is that human beings "want their cake and to eat it too."

- We want both quality and quantity
- Higher incomes and more free time
- We need profits as well as social expenditure
- Low inflation as well as high employment, and so on.

Individuals, groups, and organizations, in their decision making efforts,

- Pursue multiple objectives
- Set multiple goals
- Evaluate their options according to multiple criteria and as a consequence experience conflict.

Decision making under these conditions is characterized by incessant attempts at conflict resolution and the simultaneous attainment of goals. Milton Friedman emphasized the role of multi objective framework of thought in economics he said:

“An economic problem exists whenever scarce means are used to satisfy alternative ends. If the means are not scarce, there is no problem at all. If the means are scarce but there is only a single end, the problem of how to use the means is a technological problem. No value judgments enter into its solution; only knowledge of physical and technical relationships.”

Multi-objective decision making (MODM) occurred because of weaknesses with the conventional mathematical programming models in decision making problems. Mathematical programming models first provide feasible solutions which satisfy the constraints of the problem and then order the feasible solutions according to an objective function representing the preferences of the decision maker. The optimal solution, found from the feasible set, is the highest possible value for the objective function.

Romero and Rehman (1989) noted that the decision maker is usually not interested in ordering the feasible set according to just a single criterion but strives to find an optimal compromise among several objectives. Most decision makers are confronted with multiple, sometimes simultaneous, objectives. Another problem with using a single objective linear programming procedure lies in the restriction of commensurable units in determining an optimal solution. Furthermore, a linear programming model implies proportionality, additivity of costs, and the effects of resource uses which, in most cases, are not true. In a multiple criterion or economic problem human value judgments, tradeoff evaluations, and assessments of the importance of criteria are an integral part of the problem. MODM is a positive science in its use as compared to normative. It is positive because it attempts to explain "what is." The only likeness to a normative science is in collecting criteria weights from the preferences of individuals. There is some tie here to utility theory in how to capture individual preferences but overall MODM is not normative like the profit maximization framework or cost minimization where the emphasis is placed on "what should be."

3.2.1 GENERAL GP MODEL

More precisely, the GP designed to find a solution that minimizes the deviations between the achievement level of the objectives and the goals set for them

$$\text{Minimize } a = \{g_1 (n, p), g_2 (n, p), \ldots. g_k(n, p) \}$$

$$\text{Such that } f_i(x) + n_i + p_i = b_i$$

$$X, n, p \geq 0$$

Where; g_k is a linear function of the deviational variables. bi represents the level of aspiration associated with the objective $f_i(x)$. The variables n_i and p_i indicate the negative and positive deviations respectively of the achievement level $f_i(x)$ from aspiration level.

3.2.2 DIFFERENCE BETWEEN GP AND LP

LP identifies from the set of feasible solutions, the point that optimizes a single objective, GP determines the point that best satisfies the set of goals in the decision problem. GP attempts to minimize the deviations from the goals. GP approach requires the decision maker to specify the most desirable value (goal) for each objective as the aspiration level. The objective functions are then transferred into goals:

$$f_k(X) + d^-_k - d^+_k = a_k$$

where; a_k is the aspiration level for the kth objective, and d^-_k and d^+_k are the negative and positive goal deviations, respectively, that is, non-negative state variables that measure deviations of current value of the k_{th} criterion function from the corresponding aspiration level.

Two types of variables are part of any goal programming formulation

- The decision variables, x

- The deviation variables, d

The objective function in a goal programming problem is always minimized and must be composed of deviation variables only (decision variables are implicitly assigned coefficients of zero). An optimal solution is then understood as one that minimizes the deviations from the aspiration levels.

3.2.3 ADVANTAGES OF GP

1. The major advantage of goal programming is its computation Efficiency.
2. It allows us to stay within an efficient linear programming computational environment.
3. The weights, aspiration levels, preemptive priorities can be changed during the analysis as the decision maker’s knowledge of the decision problem changes. (Interactive Programming)

3.2.4 DISADVANTAGES OF GP

1. GP requires that the decision maker specify fairly detailed a priori information about his or her aspiration levels, preemptive priorities, and the importance of goals in the form of weights.
2. In many complex problems, it is difficult (or even impossible) for the decision maker to provide the precise information required by these methods.
3. The resulting solutions to GP may be dominated (a better solution may exist in terms of some or all of the objectives than the solution obtained through GP)
4. There is a tendency to generate inefficient solutions, the GP approach does not attempt to use additional information to find an efficient solution.

CHAPTER 4

CASE STUDY

4.1 SELECTED COMPANY

ABC Company Packaging Corporation deals with designing, manufacturing and marketing of plastic and paper packaging components for food and garden market by using the newest technologies. These products are mosly used in ice cream, chocolates, confectionary, dried fruits, olives, choco spread, halva, jam, fast food, salad, snacks, biscuits-crackers, dairy products, catering products and garden markets. ABC Company drafts the product from design to production, prototyping, mold making, material selection, fabrication, injection and labeling with integrated plant. ABC Company Packaging Corporation occupies an area of 20000 square-meters. Its products can also in use for different industries both domestic and abroad. ABC Company has production certificates like production permit and quality certificates like ISO-9001, ISO-14001, OHSAS-18001, ISO-22000 and BRC.

4.1.1 Products

Specta Vis and Lid products: These products are only manufactured by ABC Company Packaging in Turkey and Europe. Products can be produced as plastic or paper. For example yogurt boxes are being made only in this company.

- Injection Products
- Sheet Products
- Paper and Fold top products
- Special Products
- Plant and garden products
- Promotional products

4.1.2 Customers

- Nestle
- Unilever
- Solen
- Casty
- Ekici
- Kaanlar
- Kalleh
- Kwality
- Nibble Time
- Petra
- SFC
- Tahsildaroglu
- Vefa
- Hazal

These are some of the major customers of the ABC Company. There are many other customers as well.

4.2 PROBLEM DEFINITION

ABC Company is a profit making organization but it is facing certain issues. Likewise other companies, ABC Company also wants to maximize its profit as much possible. This is possible either reduce the cost or increase the selling prices. But in this competitive market, it is quite impossible to increase the selling price. So in order to maximize the profit company needs to cut short its production costs. This is the conventional objective ‘profit maximization’. In the list of priority objectives, company wants to minimize the rejection as much possible. Allowable rejection as defined by the company is 10% of the total production. If rejection goes beyond 10%, then it is a call for some remedial actions like overhauling, preventive maintenance, training of the worker, etc. Third focus area is customer satisfaction. In my model, customer satisfaction is measured by analyzing demand fulfillment. If company is fulfilling customer demand, it will be assumed that company is satisfying customers. My aim is to increase the customer satisfaction. So in a nut shell, ABC Company wants to

1.Maximize Profit

2.Minimize Rejection

3.Maximize Customer Satisfaction

To achieve these objectives, there are some constraints. ABC Company is not an economy surplus company. There are certain limitations and company has to achieve its objectives while not going beyond these limitations. As ABC Company is making packaging products, it uses two kinds of raw materials; polypropylene and labels. These raw materials are acquired from suppliers across the globe. Polypropylene is usually imported from the gulf and middle-east states. Labels are usually acquired from within the Turkey. These suppliers have certain capacity. For example ABC Company can acquire maximum 69000 kg of polypropylene form its supplier. Major constraints faced by ABC Company are as follows;

- Operational Capacity
- Supplier Capacity
- Raw Materials Balance Constraint
- Rejection Constraint
- Demand Constraint
- Inventory Constraint
- Time Limitation

4.3 METHODOLOGY

The technique I used to solve my model is goal programming as preemptive and non-preemptive goal programming. As it does not involve any kind of probability, so it comes under deterministic programming. Goal programming, introduced by Charnes and Cooper [52], deals with the problem of achieving a set of conflicting goals. The objective function searches to minimize deviations from the set of pre-assigned goals.

Goal programming can be solved in two ways:

1. Using of the simplex algorithm directly if weights given for goals are precisely defined. In a non-preemptive model, the goals are given some weights and considered simultaneously.

2. Using of the preemptive goal programming if weights given for goals are not precisely defined, but are ordered. In a preemptive goal programming model, the upper level goals are first optimized before lower level goals are considered.

In my model, I will utilize both preemptive and non-preemptive goal programming. I will utilize the solution of first goal as constraint in the second level goals which in then will be solved as non-preemptive goals because I'll assign different weightage the remaining two goals after discussing with the ABC Company officials. Some goals are more important than the others in point of view of the company. For example, in case of ABC Company packaging company, reducing the rejection is more important than demand fulfillment which in turn enhances customer satisfaction.

The challenge here is to model the system so that it can facilitate both intra- and inter-enterprise supply chain network for collecting and remanufacturing. The challenge here is to model the system so that it can facilitate both intra- and inter-enterprise supply chain network for collecting and remanufacturing.

As our model is two echelons, it involves only suppliers, manufacturer and customers.

Figure 4.1 Picture View of the Model

4.3.1 Assumptions

Every research starts with some hypothesis which defines the scope of the research and helps in the smooth conduction of the research. Before constructing model, I assumed some conditions. I assumed that model will be developed for single period. This assumption helps me to move forward stepwise. After getting satisfactory results, this research can be expanded to multi-period research. 2nd assumption is that company has only one manufacturing unit. This assumption also provides a prospect for further research so that a company with multiple manufacturing units can be studied further. After assuming production unit, there were two options for me. I could study the system for single product or multiple products. But as I selected to study aggregate production, so for aggregate production I had to study all the products being manufactured in the company so that total capacity could be analyzed and optimized.

CHAPTER 5

MODEL AND RESULTS

My model to optimize the supply chain and its results will be discussed in this chapter. As explained above, model is based on some assumptions. Summary of these assumptions is as follows;

- Only one period will be considered.
- There are multiple products.
- There is only one manufacturer.
- Production is non-preemptive.
- Aggregate production will be under consideration.

In the proceeding section of this chapter, I'll explain the mathematical model and its results.

5.1 MATHEMATICAL MODEL PHASE 1

My mathematical model is in two phases. 1^{st} phase is for preemptive model. It means that results of this phase will be used as constraint in the second phase. 1^{st} phase model and results are given below.

5.1.1 Indices

i = products

n = machines

j = suppliers

5.1.2 Decision Variables

X_{in} = number of pieces produced of product *i* on machine *n*

Y_{in} = if product *i* is processed on machine *n*

O_1 = amount of raw material to be ordered to supplier *1*

S_j = raw material amount supplied by supplier *j*

E_i = number of rejected parts of product *i*

5.1.3 Parameters

J_i = on-hand raw material inventory level when a new order will be placed

D_i= demand of product *i* per month

b = unit transportation cost from manufacturer to customer

g_i = unit production cost of product *i*

f_{in} = cycle time of product *i* on machine *n*

v_{in} = production capacity for product *i* on machine *n*

I_j = holding cost of raw material, from supplier *j*, at manufacturer

o_i = unit production cost of product *i* after rejection

L_j = Minimum amount of raw material from supplier *j* which needs to be held

M_j = supplier *j* capacity for raw material

T_n = time availability of machine *n*

ς_i = raw material *i* used for making one unit of product

μ_i = unit selling price of product *i*

5.1.4 Objective Function

$$\text{Max } \sum_i \sum_n Y_{in} X_{in} \, (\mu_i - g_i - b) - \sum_j [I_j (S_j + J_j)] - \sum_i o_i E_i \tag{5.1}$$

5.1.5 Constraints

$$\sum_i \sum_n X_{in} f_{in} \leq \sum_n T_n \tag{5.2}$$

$$X_{in} .\; Y_{in} \leq v_{in} \qquad \forall\, i \in products, \forall\, n \in machines \tag{5.3}$$

$$S_j \leq M_j \qquad \forall\, j \in suppliers \tag{5.4}$$

$$S_j + J_j + \sum_i E_i \, \varsigma_i \geq \sum_i X_{in} \, \varsigma_i \qquad \forall\, i \in products, \forall\, j \in suppliers \tag{5.5}$$

$$S_2 = \sum_i \sum_n X_{in} \tag{5.6}$$

$E_i - 0.1 \sum_n X_{in} \leq 0 \qquad \forall\, i \in products \qquad (5.7)$

$\sum_n X_{in} - E_i \geq D_i \qquad \forall\, i \in products \qquad (5.8)$

$O1 + J1 \geq L1 \qquad (5.9)$

$S1 \geq O1 \qquad (5.10)$

$\sum_i Y_{in} \geq 0 \qquad \forall\, n \in machines \qquad (5.11)$

$E_i , X_i , S_j, O_j \geq 0 \qquad (5.12)$

$E_i , X_i \in Z \qquad (5.13)$

$Y \in \{0, 1\} \qquad (5.14)$

First objective function is about profit maximization that is obtained by subtracting total cost from total selling price. This cost includes, production cost, holding cost and recycling of rejected parts cost. Second equation tells about demand fulfillment. Equation (5.2) is about how much total time we totally possess for the production required. As we have three types of machines; injection, pmc1 and pmc2, for pmc1 and pmc2 total time available is 40320 minutes because company works 28 days a month and 24 hours a day. In the injection machine type, there are totally 18 machines. If they are fully utilized then maximum time available is almost 725760 minutes per month. Equation (5.3) is about production capacity. Company can't produce beyond the limits of production. Equation (5.4) tells the supplier's capacity to supply raw material. Each supplier can supply up to a maximum amount of raw material. For example, polypropylene supplier can supply only 69000 kg of material every month and label providing supplier can provide almost 10 million labels a month. Equation (5.5) is about material balance constraint. All the raw material which includes on hand inventory of material, material supplied by the supplier and material of rejected parts will be used in making X amount of products. And residual material can be used for production in the next month. Equation (5.6) is about replenishment of labels. For labels, company can't make inventory since labels are determined according to the customers' demands. In first month customers may require one type of label. And the next month, they may require other type of labels because of some special flavors, discounts, etc. So labels will be exactly equal to the production amount of the product *i*.

Equation (5.7) says that total allowable rejections are 10 percent of the total production. If rejection goes beyond this limit, then machine needs maintenance, worker needs training or over-hauling. Equation (5.8) is for demand fulfillment. Company wants to fulfill demand but it also does not want to make inventory. So company will make exactly equal to the demand amount plus some allowable rejections. Equation (5.9) is about replenishing constraint. Company has to maintain a minimum level of polypropylene. Because it is the main ingredient in production so Company can't afford its shortage. So company is every time maintaining almost 44000 kg of polypropylene.

Equation (5.10) is about reorder quantity for polypropylene. Suppliers must have to fulfill the demand of poly propylene at least equal to as much the company demanded. Company will always order to achieve at least minimum level of raw material for polypropylene including on-hand inventory of the material. Equation (5.11) is about machine assignment. Each product will be assigned to a specific machine. As ABC Company has 3 types of machines; injection, pmc1 and pmc2. So this constraint binds each product to be processed on one machine type implying that that product has some demand. If there is no demand for a product, it will not be processed on any machine and Y will take zero value as Y is a binary variable. In the end equations (5.12) and (5.13) are about non-negativity of E_i , X_i , S_j , Jj and integer property for E_i and X_i respectively. Equation (5.14) says that Y is a binary variable. If a product i is made on machine n then Y takes value 1 for that product on a specific machine otherwise it will be zero.

5.1.6 Results Of Phase 1

After solving the model in AMPL according to the data provided by ABC Company, it turned out that company can make almost 4 million Turkish Lira profit per month, with the exact figures 3917990 TL. This profit is exclusive of taxes and without any rejection. If there are rejections, it will lower the company's profit. That's why through this study, company was made realize how much profit it can earn if rejection is minimized. Rejection can be controlled by applying Lean principles, implementing 5S, total preventive maintenance, training of employees and by other state of the art techniques. As the company doesn't want to make inventory so it will order labels according to the demand of the products. Because each month same product may require different labels as per marketing needs. Suppliers will supply the maximum limit of the polypropylene that is 69000 kg.

Table 5.1 Results of Phase 1: Profit and Raw Material Amount

Profit	**3917990**	
	Supplied amount	Ordered Amount
Label	10500000	0
Polypropylene	69000	0

Production amount of each product is being showed below. Some of the regular products have no demand in the month of May for which system was being studied. As the company wants to minimize the rejection, so the software shows this rejection to be zero. Moreover, some of the products are required to be made on injection machines and some are required to be made on PMC1 and PMC2. So AMPL showed zero for PMC1 and PMC2 if product is to be made on injection machine. So for injection machine the value is equal to the demand of that particular product. For example, E117 is a product which is to be made on injection machine in amount 270000. So software will return 270000 items of E117 to be made on injection machine and zero values for PMC1 and PMC2. Some products have no demand, so they will not be made in any quantity.

Table 5.2 (Cont.) Results of Phase 1: Production amount of each product

	Demand	**Injection**	**PMC 1**	**PMC 2**	**Rejection E**
E101	0	0	0	0	0
E101_1	0	0	0	0	0
E103	0	0	0	0	0
E104	0	0	0	0	0
E104_1	0	0	0	0	0
E105	0	0	0	0	0
E105_1	0	0	0	0	0
E106	0	0	0	0	0

Table 5.2 (Cont.) Results of Phase 1: Production amount of each product

E106_1	0	0	0	0	0
E106_2	0	0	0	0	0
E107	0	0	0	0	0
E107_1	0	0	0	0	0
E109	0	0	0	0	0
E109_1	0	0	0	0	0
E110	0	0	0	0	0
E113	0	0	0	0	0
E115	0	0	0	0	0
E116	0	0	0	0	0
E117	250000	250000	0	0	0
E118	262500	262500	0	0	0
E119	0	0	0	0	0
E120_1	100000	100000	0	0	0
E121	0	0	0	0	0
E123	0	0	0	0	0
E124	34800	348000	0	0	0
E125	0	0	0	0	0
E126	0	0	0	0	0
E127	0	0	0	0	0
E128	0	0	0	0	0
E129	0	0	0	0	0
E129_1	0	0	0	0	0
E130	0	0	0	0	0
E130_1	0	0	0	0	0
E132	0	0	0	0	0
E133	108000	108000	0	0	0
E134	0	0	0	0	0
E135	0	0	0	0	0
E137	20000	200000	0	0	0
E138	20000	200000	0	0	0
E139	10000	10000	0	0	0
E140	10000	10000	0	0	0
E141	0	0	0	0	0
E142	0	0	0	0	0
E143	0	0	0	0	0
E144	20000	20000	0	0	0
E145	20000	20000	0	0	0
E146	0	0	0	0	0
E147	0	0	0	0	0
E148	0	0	0	0	0

Table 5.2 (Cont.) Results of Phase 1: Production amount of each product

E149	**0**	**0**	**0**	**0**	**0**
E150	0	0	0	0	0
E151	0	0	0	0	0
E152	0	0	0	0	0
E153	0	0	0	0	0
E154	0	0	0	0	0
E155	0	0	0	0	0
E156	0	0	0	0	0
E157	0	0	0	0	0
E158	0	0	0	0	0
E161	0	0	0	0	0
E162	0	0	0	0	0
E163	0	0	0	0	0
E164	0	0	0	0	0
E167	0	0	0	0	0
E168	0	0	0	0	0
E169	100000	100000	0	0	0
E170	200000	200000	0	0	0
E171	0	0	0	0	0
E172	0	0	0	0	0
E173	0	0	0	0	0
E174	0	0	0	0	0
E175	0	0	0	0	0
E176	0	0	0	0	0
E177	1000	1000	0	0	0
E178	0	0	0	0	0
E179	0	0	0	0	0
E180	0	0	0	0	0
E181	300000	300000	0	0	0
E182	300000	300000	0	0	0
E183	0	0	0	0	0
E184	50000	50000	0	0	0
E185	0	0	0	0	0
E186	0	0	0	0	0
E187	300000	300000	0	0	0
E188	270000	270000	0	0	0
E189	24000	0	0	24000	0
E190	0	0	0	0	0
E191	0	0	0	0	0
Eomr	0	0	0	0	0
Eomri	0	0	0	0	0

Table 5.2 Results of Phase 1: Production amount of each product

FLT1000	390000	0	390000	0	0
FLT500	0	0	0	0	0
FLT750	280000	0	280000	0	0
PAP1000	0	0	0	0	0
PAP1250	0	0	0	0	0
PAP1750	0	0	0	0	0
PAP230	30000	0	30000	0	0
PAP2500	100000	0	0	100000	0
PAP470	180000	0	180000	0	0
PAP500	0	0	0	0	0
PAP550	225000	0	225000	0	0
PAP750	96000	0	96000	0	0
SL1000	0	0	0	0	0
SL1000_1	0	0	0	0	0
SL1000_2	0	0	0	0	0
SL1000_3	23000	0	0	23000	0
SL430	0	0	0	0	0
SL430_1	0	0	0	0	0
SL500	0	0	0	0	0
SL500_1	120000	0	0	120000	0
SV1000	63500	0	63500	0	0
SV1250	151200	0	0	151200	0
SV1750	0	0	0	0	0
SV230	115500	0	0	115500	0
SV2500	35000	0	0	35000	0
SV430	0	0	0	0	0
SV470	422500	0	422500	0	0
SV500	24000	0	24000	0	0
SV600	600000	0	0	600000	0
SV750	276400	0	276400	0	0

The results of the first step were used in the second stage. Second stage was solved by goal programming in a non-preemptive way. It means that different weights were assigned to two different goals. Weights were assigned after discussion with the ABC Company management. As company has different priority for different objectives. Company considers that controlling the rejection is more important that fulfilling customer demand. In other sense, company thinks that if they could control the rejection, it will help them in fulfilling the customer demand. So minimizing the rejection was given higher weight than demand fulfillment. As goal programming is all about deviations. So I used minimizing the positive deviation of rejection limit and minimizing the negative deviation of the demand fulfillment as company wants to maximize the customer satisfaction so company needs to minimize the negative deviation which shows shortage. This shortage creates backlog which in turn disturbs the entire production planning of the future months. As long the weights are concerned, rejection minimization was given 55% and demand fulfillment was given 45% weight. Mathematical model for this stage is explained below.

5.2 MATHEMATICAL MODEL PHASE 2

All the indices, parameters and decision variables are same as the previous phase with only some new decision variables which are deviations being used in goal programming. These decision variables and their descriptions are as follows;

d1 = negative deviation for rejection constraint

d2 = positive deviation for rejection constraint

d3 = negative deviation for demand constraint

d4= positive deviation for demand constraint

5.2.1 Objective Function

Minimize 0.55 d2 + 0.45 d3 (5.15)

5.2.2 Constraints

$\sum_i \sum_n Y_{in} X_{in} \, (\mu_i - g_i - b) - \sum_j [I_j(S_j + J_j)] - \sum_i o_i E_i = 3917990$ (5.16)

$\sum_i \sum_n X_{in} f_{in} \leq \sum_n T_n$ (5.17)

$X_{in}.\ Y_{in} \leq v_{in}$ $\forall\, i \in products, \forall\, n \in machines$ (5.18)

$S_j \leq M_j$ $\forall\, j \in suppliers$ (5.19)

$S_j + J_j + \sum_i E_i\, ç_i \geq \sum_i X_{in}\, ç_i$ $\forall\, i \in products, \forall\, j \in suppliers$ (5.20)

$$S_2 = \sum_i \sum_n X_{in} \tag{5.21}$$

$$E_i - 0.1 \sum_n X_{in} + d1 - d2 = 0 \qquad \forall\, i \in products \tag{5.22}$$

$$\sum_n X_{in} - E_i + d3 - d4 = D_i \qquad \forall\, i \in products \tag{5.23}$$

$$O1 + J1 \geq L1 \tag{5.24}$$

$$S1 \geq O1 \tag{5.25}$$

$$\sum_i Y_{in} \geq 0 \qquad \forall\, n \in machines \tag{5.26}$$

$$E_i\, ,\, X_i\, ,\, J_j \geq 0 \tag{5.27}$$

$$E_i\, ,\, X_i \in Z \tag{5.28}$$

Here all the commentary is same as that of phase 1. The only difference is the objective function and the first constraint. Objective function shows that this is non-preemptive because different weights have been assigned to two different goals after discussing with the management of the company. Minimizing the rejection has more weight in eyes of top management so it is assigned 55% weight while customer satisfaction is awarded 45% weight. Equation 5.16 is actually the objective function of the first goal that was a profit maximization goal. Profit will always be considered as achieved by solving the first goal. Equations 5.22 and 5.23 are similar in nature. Both depict that whenever there is an inequality and it has to convert into equality then it tends to possess either positive deviation or negative deviation. These deviations constitute the objective function. Rest of the constraints is similar as described in the phase 1.

5.2.3 Results of Phase 2

Profit of the company is shown same but if there are some rejections (as company allows 10% rejection of the overall production) then in this case company can suffer its profit. 7339560 labels and 59510 kg of polypropylene will be ordered. Here supplier will supply the same amount of polypropylene as much it will be ordered. Ordered quantity is 59510 kg and supplied quantity is also 59510 kg. Deviational variables for demand and rejection show zero values. It means demand is exactly met without any shortage or excess. And there is no wastage beyond 10%.

Table 5.3 Results of Phase 2: Profit and Raw Material Amount

	Profit	3917990
	Supplied amount	Ordered Amount
Label	7339560	0
Polypropylene	59510	59510

dev = 0
d1 = 0
d2 = 0
d3 = 0
d4 = 0

Following table shows the production amount of all the products. This table shows not only the production data but also it includes rejection data. If there is no demand for any product, its production amount will be zero.

Table 5.4 (Cont.) Results of Phase 2: Production amount of each product

	Demand	Injection	PMC1	PMC 2	Rejection
E101	0	0	0	0	0
E101_1	0	0	0	0	0
E103	0	0	0	0	0
E104	0	0	0	0	0
E104_1	0	0	0	0	0
E105	0	0	0	0	0
E105_1	0	0	0	0	0
E106	0	0	0	0	0
E106_1	0	0	0	0	0
E106_2	0	0	0	0	0
E107	0	0	0	0	0
E107_1	0	0	0	0	0
E109	0	0	0	0	0

Table 5.4 (Cont.) Results of Phase 2: Production amount of each product

E109_1	**0**	**0**	**0**	**0**	**0**
E110	0	0	0	0	0
E113	0	0	0	0	0
E115	0	0	0	0	0
E116	0	0	0	0	0
E117	250000	277778	0	0	27777
E118	262500	291667	0	0	29166
E119	0	111111	0	0	11111
E120_1	100000	111111	0	0	11111
E121	0	0	0	0	0
E123	0	222222	0	0	22222
E124	34800	386667	0	0	38666
E125	0	0	0	0	0
E126	0	0	0	0	0
E127	0	0	0	0	0
E128	0	0	0	0	0
E129	0	0	0	0	0
E129_1	0	0	0	0	0
E130	0	0	0	0	0
E130_1	0	0	0	0	0
E132	0	0	0	0	0
E133	108000	120000	0	0	12000
E134	0	0	0	0	0
E135	0	0	0	0	0
E137	200000	222222	0	0	22222
E138	200000	222222	0	0	22222
E139	10000	11111	0	0	1111
E140	10000	11111	0	0	1111
E141	0	0	0	0	0
E142	0	0	0	0	0
E143	0	0	0	0	0
E144	20000	22222	0	0	2222
E145	20000	22222	0	0	2222
E146	0	0	0	0	0
E147	0	0	0	0	0
E148	0	0	0	0	0
E149	0	0	0	0	0
E150	0	0	0	0	0
E151	0	0	0	0	0
E152	0	0	0	0	0
E153	0	0	0	0	0

Table 5.4 (Cont.) Results of Phase 2: Production amount of each product

E154	0	0	0	0	0
E155	0	0	0	0	0
E156	0	0	0	0	0
E157	0	0	0	0	0
E158	0	0	0	0	0
E161	0	0	0	0	0
E162	0	0	0	0	0
E163	0	0	0	0	0
E164	0	0	0	0	0
E167	0	0	0	0	0
E168	0	0	0	0	0
E169	100000	111111	0	0	11111
E170	200000	222222	0	0	22222
E171	0	111111	0	0	11111
E172	0	0	0	0	0
E173	0	0	0	0	0
E174	0	0	0	0	0
E175	0	0	0	0	0
E176	0	0	0	0	0
E177	1000	1111	0	0	111
E178	0	0	0	0	0
E179	0	0	0	0	0
E180	0	0	0	0	0
E181	300000	333333	0	0	33333
E182	300000	333333	0	0	33333
E183	0	0	0	0	0
E184	50000	55555	0	0	5555
E185	0	0	0	0	0
E186	0	0	0	0	0
E187	300000	333333	0	0	33333
E188	270000	300000	0	0	30000
E189	24000	26666	0	0	2666
E190	0	0	0	0	0
E191	0	0	0	0	0
Eomr	0	0	0	0	0
Eomri	0	0	0	0	0
FLT1000	390000	0	433333	0	43333
FLT500	0	0	0	0	0
FLT750	280000	0	311111	0	31111
PAP1000	0	0	0	0	0
PAP1250	0	0	0	0	0

Table 5.4 Results of Phase 2: Production amount of each product

PAP1750	**0**	**0**	**0**	**0**	**0**
PAP230	30000	0	33333	0	3333
PAP2500	100000	0	0	111111	11111
PAP470	180000	0	200000	0	20000
PAP500	0	0	0	0	0
PAP550	225000	0	250000	0	25000
PAP750	96000	0	106667	0	10666
SL1000	0	0	0	0	0
SL1000_1	0	0	0	0	0
SL1000_2	0	0	0	0	0
SL1000_3	23000	0	0	0	0
SL430	0	0	0	0	0
SL430_1	0	0	0	0	0
SL500	0	0	0	0	0
SL500_1	120000	0	0	0	0
SV1000	63500	0	70555	0	7055
SV1250	151200	0	0	168000	16800
SV1750	0	0	0	0	0
SV230	115500	0	0	0	0
SV2500	35000	0	0	38888	3888
SV430	0	0	0	0	0
SV470	422500	0	469444	0	46944
SV500	24000	0	26666	0	2666
SV600	600000	0	0	0	0
SV750	276400	0	307111	0	30711

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

In this thesis, I focused on enhancing the effectiveness of the supply chain management by means of goal programming. My focus was on supply chain network design with a concern to minimize the rejection and maximize the customer satisfaction by fulfilling demand. In supply chain there are many stake holders; suppliers, manufacturers, distribution centers and retailers, customers and many others. Strategic decisions on establishing a supply chain network (SCN) encompass more than one criterion. For example, a conventional criterion for supply chain is cost optimization. But there can be many other criteria. For example customer service levels, environmental and quality issues, supplier selection, solid waste management, etc. These objectives are usually incompatible, as they usually involve trade-offs. As the number of criteria increases, there will be no effect on the theoretical domain of the problem but the formulation and computation time will increase. Additionally the complexity of the problem will also increase. So to make the situation clear and easier, three objectives (criteria) will be chosen.

1.Conventional supply chain objective; cost minimization
2.Minimizing the rejection
3.Maximizing the demand fulfillment

If there is any part which can be recycled then it should be used as much as possible because it will not only reduce the total cost of the supply chain but also it will reduce environmental issues. In the end it is also a cost minimizing element.

These objectives will be analyzed along with constraints such as demand, supply, operational capacity, holding capacity and rejection constraints of a particular product by means of optimization software like AMPL. In this research, estimated demand from various retail units, capacity commitment by the suppliers, assemblers and ware houses have been considered as constraints in order to develop a multiple-objective decision –

making model for the choice of warehouses and recyclable amount for a supply chain network (SCN) design. The SCN is considered for the production of multiple products. It will be shown that compared to the optimal solution generated by considering only one objective differs when two objectives are considered simultaneously.

6.2 RECOMMENDATIONS

1. This study was conducted for single period. To enhance the scope of the study, it can be expanded for multiple periods.
2. This model can be studied with different modeling techniques. Like Chance Constraint Goal Programming, Swarm Optimization, Genetic Algorithm, etc.
3. One of the most important things at the end of optimization problems is Sensitivity Analysis of the model which could not be performed because of the time issues.

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APPENDIX

APPENDIX 1

As we solved this model in AMPL, in which we need to construct its model file. Model file is made in notepad. After making this file, it is saved with .mod extension and called on AMPL. There are certain rules for writing the code of model. An instance of our model files is being shown. This model file is for phase that is preemptive goal planning. Its result will be used in the second level phase.

```
set products;
set suppliers;
set machines;

var X{products,machines} >= 0 , integer;
var Y{products, machines} binary;
var S{suppliers}>= 0;
var O{suppliers}>= 0;
var E{products} >=0 , integer;

param J {suppliers};
param D{products};
param b;
param g{products};
param f{products, machines};
param v{products, machines};
param I{suppliers};
param o{products};
param L{suppliers};
```

```
param M{suppliers};
param T{machines}
param c{products};
param p{products};
maximize profit:
sum{i in products, n in machines} X[i, n]* Y[i,n] * p[i] -  sum{ii in products, nn in
machines} X[ii,nn]* Y[ii,nn] * g[ii]- sum{iii in products, nnn in machines} X[iii,nnn]*
Y[iii,nnn] * b - sum {j in suppliers} I[j] * S[j] - sum{jj in suppliers} I[jj] * J[jj] -
sum{iiii in products} o[iiii] * E[iiii];

subject to time_const:
sum{i in products, k in machines} X[i,k] * f[i,k]  <=  sum {n in machines} T[n];

subject to prod_cap_const {i in products, n in machines}:
X[i,n] * Y[i,n] <= v[i,n];

subject to supplier_const {j in suppliers}:
S[j] <= M[j];

subject to raw_mat_balance_const {j in suppliers, n in machines}:
S[j] + J[j] + sum{i in products}E[i]*c[i] >= sum{ii in products}X[ii,n]*c[ii];

subject to replinish_const:
S["label"] = sum{i in products, n in machines} X[i,n];

subject to reject_const {i in products}:
E[i] - 0.1*sum{n in machines}X[i,n]  <= 0;

subject to customer_satisfaction_const {i in products}:
sum {n in machines} X[i,n] - E[i] >= D[i];
```

```
subject to reorder_const_1 :
O["polyprop"] >= L["polyprop"] - J["polyprop"];

subject to reorder_const_2:
S["polyprop"] >= O["polyprop"];
subject to machine_assign_const {n in machines}:
sum{i in products} Y[i,n] >= 0;
```

APPENDIX 2

Results of preemptive phase are used in the second level that is non-preemptive phase. Here different weights are assigned to two different goals. These weights are assigned after discussion with the company personnel. This phase was also solved on AMPL. Its model file is being shown here.

```
set products;
set suppliers;
set machines;

var X{products,machines} >= 0 , integer;
var Y{products, machines} binary;
var S{suppliers}>= 0;
var O{suppliers}>= 0;
var E{products} >=0 , integer;
var d1 >=0;
var d2 >=0;
var d3 >=0;
var d4 >=0;
param J {suppliers};
param D{products};
param b;
param g{products};
param f{products, machines};
param v{products, machines};
param I{suppliers};
```

```
param o{products};
param L{suppliers};
param M{suppliers};
param T{machines};
param c{products};param p{products};

minimize dev:
0.55*d2+ 0.45*d3 ;

subject to time_const:
sum{i in products, k in machines} X[i,k] * f[i,k]  <=  sum {n in machines} T[n];

subject to prod_cap_const {i in products, n in machines}:
X[i,n] * Y[i,n] <= v[i,n];

subject to supplier_const {j in suppliers}:
S[j] <= M[j];

subject to raw_mat_balance_const {j in suppliers, n in machines}:
S[j] + J[j] + sum{i in products}E[i]*c[i] >= sum{ii in products}X[ii,n]*c[ii];

subject to replinish_const:
S["label"] = sum{i in products,n in machines} X[i,n];

subject to reject_const {i in products}:
E[i] - 0.1*sum{n in machines}X[i,n] +d1 -d2  = 0;

subject to customer_satisfaction_const {i in products}:
sum {n in machines} X[i,n] - E[i]  +d3 - d4 = D[i];

subject to reorder_const_1 :
O["polyprop"] >= L["polyprop"] - J["polyprop"];

subject to reorder_const_2:
```

```
S["polyprop"] >= O["polyprop"];

subject to machine_assign_const {n in machines}:
sum{i in products} Y[i,n] >= 0;
subject to profit:
sum{i in products, n in machines} X[i, n]* Y[i,n] * p[i] -  sum{ii in products, nn in
machines} X[ii,nn]* Y[ii,nn] * g[ii]- sum{iii in products, nnn in machines} X[iii,nnn]*
Y[iii,nnn] * b - sum {j in suppliers} I[j] * S[j] - sum{jj in suppliers} I[jj] * J[jj] -
sum{iiii in products} o[iiii] * E[iiii] <= 3917990;
```