A DEFECTIVE GOODS SUPPLY CHAIN COST OPTIMIZATION MODEL CONSIDERING REWORK OF DEFECTIVES

By

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CERTIFICATE OF APPROVAL

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Md. Farhad Hasan Azad

To my father.

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ABSTRACT

Supply chain is the coordination and synchronization of the flow of resources in the network of suppliers, manufactures, distributors and customers. The flow passes through different entities which individually have their own performance measures and objectives. In recent years, Supply Chain Management has received an increased amount of interest both from researchers and in the industry. Many concepts for supply chain design and modeling have been presented with different focuses. Most of the classical production models assume that all goods produced by manufacturer are perfect quality. But, in practice, imperfect goods production is quite inevitable. So, the effects of these defective goods need more focus by the researchers as an essential concern in supply chain cost optimization. Defective goods have always been a part of the production process that affects the overall costs, time and quality which are the major logistics performance. This study is to develop a new model for defective goods supply chain cost optimization which has the goal of fulfilling and grasping some new research opportunities in the field of supply chain cost optimization. This work addresses different types of supply chain costs considering the rework in order to capture its dynamic behavior. The proposed model is formulated to optimize the total supply chain cost considering the defective items within the chain. The model is applied to two real-world supply chains with different value streams for proving its functionality. Genetic Algorithm has been chosen to apply in this model because of its usability, availability and high probability of reaching the global optimum. The results are compared with that of LINPROG in order to demonstrate the model equations and their behavior. A sensitivity analysis is used in this study to determine the robustness and consistency of the behavior of the model under different methods, variables or assumptions. The analyses of results provide strong indications that the methodology and model introduced in this study are capable to generate knowledge to support academic research and real-world decision making regarding supply chain. Proper required index, parameters, and variables have been introduced to add more flexibility to the model implementation. In addition, the service costs and the possibility of shortage of materials at the delivery stage have been taken into account in the model that makes the model more realistic. Different viable data and sources enable the assembly of the model and provide more transparency of the results. Although this model is tested by two companies, it can be extended in any other company. Thus, the applications of the model are not limited to specific stages or levels of the chain. Moreover it has become the platform for the researcher that can unearth some interesting scopes for further research in this specific area.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In reviewing the prevailing literature, articles, books and magazines available, it is clear that one common definition of Supply Chain Management (SCM) does not exist. However, it can be defined as the systematic analysis and educated decision-making within the different business functions of an organization resulting in smooth and cost-effective flows of resources- material, information, and money. In other words, it is the coordination and synchronization of the flow of resources in the network of suppliers, manufacturing facilities, distribution centers‟ and customers [1].The chain links suppliers and customers, beginning with the production of raw material by a supplier, and ending with the consumption of a product by the customer. In a supply chain, the flow of goods between a supplier and a customer passes through different entities like suppliers, manufacturers, distributors, and retailers, which individually have their own performance measures and objectives to optimize.

Today Supply Chain Management has received an increased amount of interest both from researchers and in the industry. The SCM concept came up just before the 1960s [2]. The study of SCM increased in the 1980s and had a dramatic increase in the 1990s. More and more companies have to focus on their supply chain in order to be successful in their business. M. Christopher and D. R. Towill describe the trends for Supply Chain Management from the beginning of the eighties to end of the nineties [3]. In the beginning of the eighties the focus was on cost effective supply chains. During the coming years quality was in focus and then in the end of eighties the focus went back to cost.

To be able to survive on the market the companies have to cut cost in all areas and focus on SCM. Researcher are continuously studying to make changes to the supply chain helps to lower cost and enables a company to more easily compete based on the price. Many concepts for supply chain design and supply chain modeling have been presented during the last few years with different focus. Therefore, management of supply chains in a business environment has a major financial impact on all parties involved in the chain. Due to that, research and implementation of supply chain management principles to improve the supply chain are of key importance to any global company today.

A company needs to have performance measurements to be able to evaluate the efficiency of the supply chain. One can‟‟t manage if one can‟t measure. M. Christopher claimed that companies have to achieve both cost leadership and service leadership to have an efficient supply chain [4]. Defective goods have always been a part of the production process and there are several decisions made in its different functions and progression of supply chain processes which each of them affects the overall logistics costs, time and quality which are the major logistics performance. The economic production quantity is one the most important factor to get the optimal solution which gives the lowest cost but best performance (cost, quality, time), especially in the essential and costly processes.

In recent decades, the optimization methodology and the development of its principles and concepts have widely been applied in supply chain management. Contributors of a supply chain, no matter to which industry they belong, aim to minimize the total cost to make their business processes more and more efficient in order to survive on the market. It is essentially about increasing the efficiency, eliminating wastage or defectives, and bringing new ideas by using empirical methods. In today"s highly competitive global marketplace, companies and organizations need to find new ways to avoid waste through the appropriate decisions and efficient operations of their systems. In other words, using new methods and tools to optimize their systems is the key factor to leverage their effectiveness and to retain competitiveness. Hence, this study is about system cost optimization considering the defective item within the system which includes all desired objectives and related costs and constraints in the calculation that will help the company to make the effective and efficient supply chain decision and design.

1.2 Research Background and Motivations

Principally, the business context and the optimization concept have the same goal. They both try to reach the objective functions that are maximizing profit or minimizing cost bounded by the certain constraints which are the limited resources, budget, capacity, and so on. Therefore, the company should take the optimization concept as the framework to carry out in every process to achieve the maximum level of the desired competitive advantages, the cost leadership and service leadership from the supply chain.

Today the manufacturers are really confused to make the appropriate decision to get the optimum supply chain output due to the generation of defective goods in the circumstances of a variety of products, increased customer"s expectation and rapid industrial growth. In this situation, it is come into view that many manufacturers are not considerate of defective products and its impacts where some others use these unconsciously. So it is high time to rethink the actual effects of defective good on supply chain decision making.

Supply chain management has become one of the most popular and fastest growing areas in management. Academic journals publish myriad of articles on supply chain management, universities offer courses and even programs on supply chain management and companies successfully implement approaches and strategies offered by supply chain management. One major issue of SCM, among others, is making appropriate decision to serve customers effectively (high customer service) and efficiently (low costs), involving upstream and downstream partners (suppliers, customers). This is particularly difficult as companies nowadays face a series of challenges like shrinking product lifecycles, the proliferation of product variants, and increasing uncertainty on both the demand and the supply side due to defective items. Besides, the decisions such as selection of supplier, freight forwarder, transportation route, transportation mode, the purchasing and planning parameters setting (Optimal Production Quantity, Defective products, Scrap products, Safety stock etc.) are also the important activities significantly affecting on the overall organizational cost and performance. Hence, all concerning costs and impacts should be taken into consideration in order to choose the optimal value that best meets the organization"s shared objective.

Today"s business firms are giving more attention towards their supply chain cost optimization**.** The company deals and communicates with each and every element of the supply chain to achieve the success. X Steel Limited (XSL) is the most prominent manufacturer of transmission and telecom steel tower which is employing and servicing nation not only across Bangladesh but also different countries around the world. Though the production of steel towers is labor and machine intensive, the XSL which has low labor cost and efficient production machinery that offers the strength and competitive advantage with low production cost. But the raw materials cost to do the job is so high. However, the manufacturing of the steel towers is combined of manual and automated machineries, the factories endure the high logistics cost and time due to rework the defective items that makes the management difficult to make decisions. Hence, the company realizes this hinder and searches for the comprehensive way to make the defective good supply chain more efficient by reducing the total cost through mathematical programming. These practical experiences while working in this prominent company initially triggered off a motivation to the researcher to work on this problematic area.

Such embryonic concept is the genesis of making interested initially to do a survey on available research papers and articles to identify the respective scope of contribution on decision making of defective goods supply chain network. By observing the study result there will be a better understanding of why and what matters should consider and how can execute the supply chain cost minimum in such type of factory. The relevance between the embryonic concept and the available research papers has made more enthusiastic over carrying on this study to make it something innovative and interesting.

A comprehensive literature survey, presented in Chapter 2, will shows that most of the researches conducted on total cost optimization considering defective goods SCM are considerably heterogeneous and fragmented. The study results suggest that business has not yet fully operationalized the concept of supply chain management. Some authors even argue that SCM does not have its own "theory" [5]. Hence, it might be useful to contribute to the theory of SCM by trying to better organize the available concepts and approaches. Therefore, the first goal of this study is to use the Operations Research triangle to build a conceptual model of cost optimization in defective goods supply chains from existing literature. The sparse estimation-based empirical research that does exist indicates that cost optimization based upon the thoughts of SCM still cannot be considered as fully implemented in many supply chains.

Thus, to go from traditional arm‟s length agreements where only internal short-term costs have been in focus, to scientific approach of total cost minimization, seems to be a difficult task for companies, despite the many obvious advantages mentioned in the literature in Chapter 2. Perhaps one reason is that SCM, still after twenty years, is a blurry and not very well defined expression [6]. In fact, there is a problem with the lack of a well-defined SCM expression, which the parties involved, agree upon. Apart from the facts that supply chain cost minimization based upon SCM is still something unusual. There also exist a gap between the ideas behind the concepts and empirical research about the promised effects of defective goods.

Practical experiences in different companies and the available theoretical literatures motivate that more incorporate research into the effects of defective goods in total cost concerning different type factories is needed. Still, considerable research efforts are required before we can reach the goal of being able to understand what kind of decision is successful in different situations. There is currently a little descriptive research available on how manufacturers make their decisions in logistics forecasting, planning and production. Practice-oriented case studies as well as surveys from not only the USA or Europe but also different 3rd world developing countries like Bangladesh would be very valuable. In such countries the change from the traditional concepts into available theoretical concepts is more difficult and involves many problems. Furthermore, research concerning effects of defective goods in cost optimization is incongruous and sporadic which is often only based on single best practice cases (such as Wal-Mart). The aim of this study is to address all these sporadic factors in one mathematical model.

As a consequence of increased globalization, the competition among companies is growing and new ways have to be found to succeed in the new business climate. During the 1980s and 1990s a new trend towards integration and collaboration in supply chain instead of so-called arm‟s-length agreements between suppliers and customers has been recognized by researchers as well as business practitioners. Actors participating in the same supply chain identify tradeoffs with their adjacent customers and suppliers and have started to realize the importance of integration in the chain in order to focus on supply chain cost minimization and efficiency. Internal excellence is not enough anymore; there is also a need for external excellence in the whole supply chain. This management philosophy is called modern supply chain management which has received enormous attention in research journals as well as in industry and consultancy firms [4].

After examining the supply chain more closely, it is clear to see that it is a complex system that consists of multiple actors, e.g., suppliers, manufacturers, distributors, and retailers, which independently have their own performance measures and aims. These actors strive toward their own purposes at different levels, which in most cases are in conflict with each other, which have to be taken into account in their operations. Thus, due to the multiple performance measures, supply chain decision making is much more complex than treating it as a single objective optimization problem. Hence, while the retailer might aim to minimize the product price and lead time, the distributor might measure upon its ability to fully utilize the warehouse and the stock keeping-units, the manufacturers are searching new ways to optimize their systems through the appropriate decisions and efficient operations.

The manufacturers have a particular set of key performance measures. Manufacturer focuses on maximizing the throughput with quality, minimizing the work-in-process along with optimizing its production lot quantity and set-up times, delivery time and as well as maximize service levels. However, optimizing the cost of these individual entities is not sufficient when optimizing a supply chain as it is a dynamic network consisting of multiple points with complex information and financial transactions between entities. SCM is thus multi-objective in nature and involves several conflicting objectives, both at the individual entity level and at the supply chain level. Though, 9% of the studies consider multiple objectives while 75% of the studies featured solely minimization of cost in Supply Chain Network Design (SCND) [7]**,** optimizing the supply chain as a whole is as critical as optimization of the individual entities. This study aims to align and combine all the multiple points with complex information and financial transactions from the manufacturer‟s perspective which will greatly influences the other entities to work together towards a common goal- increasing the efficiency and profitability of the overall supply chain.

In general, optimization modeling approach ensuing mathematical programming, require equation-based models of the system under study. The models also require a comprehensive knowledge of optimization from the developers and most real-world problems are too complex to be formulated as manageable mathematical equations. Most of the classical production models assume that all goods produced by manufacturer are characterized by perfect quality. But, in practical, imperfect goods production is quite inevitable [8]. So, the effects of these defective goods need more focus by the researchers as an essential concern in supply chain optimization. Hence, in a supply chain optimization problem, the supply chain needs to be depicted through mathematical modeling, in order to capture its dynamic behavior, and to be combined with optimization methods to attain optimal solution sets. Actually, such an idea can be found in much earlier publications by researchers. They discussed the use of multi-criteria utility functions.

A comprehensive literature survey, presented in Chapter 2, shows that most of the research conducted on cost optimization for SCM is based on mathematical approaches, e.g., linear programming, mixed integer programming, mixed integer linear programming etc. Even if, Genetic Algorithm (GA) has been described as the most effective tool for designing and analyzing systems, it is very often misunderstood in industry that simulation, if used standalone, is not a real optimization tool. In comparison with the large amount of publications on applying Genetic Algorithm approaches to SCM problems, it seems that the exploration of using GA-based optimization, especially within the context of defective goods supply chain optimization, is far from adequate. This research has been focused on integrating generative tools so that "optimal" or close to optimal solutions can be found automatically. An optimal solution here means the setting of a set of controllable decision variables that can minimize or maximize some measures of system performance.

This research is initiated to fulfill an aim to facilitate the manufacturers in decision making regarding the cost and performance of a defective goods supply chain. The focus of this study is to present a novel method and model for measuring supply chain cost and performance and to suggest a quantitative method to evaluate the efficiency. Practical experiences in different factories and different empirical data from different consultants are the initial motivation to do this study in this area. Performance measurements and efficiency measurements concerning the imperfect items have been two interesting areas during this time that provided the enthusiasm to do something to make the manufacturer concerned about making the appropriate decisions to optimize the total cost. This has been a great inspiration to do this work. The practical environment while calculating the cost of supply chain due to defectives at factories, a broad literature review, many interviews of other companies consultants, and a strong supervision of the supervisor are the influential factors that have inspired and motivated to such research by avoiding general categorical statements based only on intuition.

To conclude the background motivation so far, it can be stated that despite more than two decades of discussion about SCM and its many promising effects, both by researchers and by consultants, little SCM can be found in real. In terms of methodology there is a gap between analytical research, which is often very stylized, and case study research, which is often just anecdotal. This study suggests a quantitative modeling using empirical (real-world) data. Therefore, the conceptual cost minimization model of defective goods SCM is tested by means of the analysis of real world supply chains out of different industries. The goal is to gain further insight concerning the impact of imperfect goods on supply chain efficiency. Although some classical models have been developed, none of them got so far because they were either sporadic or not suitable for all manufacturers as some are considering rework and some are not. This integrated study examine the alternate way to better design by means of an innovative application of the standard tools and methods with all relevant costs and constraints from all concerning parties to get the most efficient supply chain.

1.3 Research Aims and Objectives

This paper is written within the Supply Chain Management area considering defective goods and focus will be on the efficiency of the supply chain and to be more specific the cost as the manufacturer aspect. The aim of the thesis is to be clear as manufacturer, what effects the defective goods really have on the supply chain efficiency by analyzing theoretical and practical evidences.

Supply Chain Management has a wide scope in the literature on SCM and there are a lot of models describing the Supply chain from different perspectives. Some models are describing how to set up a supply chain based on product mixes, locations, inventory planning etc. Other models describe what to measure in the supply chain.

The objective of Supply Chain Management is to minimize the total supply chain cost and to meet the given demand. Costs considering the defective goods in the supply chain most likely affect the performance like delivery precision and lead-time. It can be balanced the cost and lead-time by doing rework, but rework cost can affect the total cost for some product noticeably. The challenge for a company is to combine the cost and performance, and optimize both of them to get the best result for the company.

The most efficient Supply chain is the one that has the lowest possible cost and at the same time meet the customer‟s expectations on service like delivery precision and lead-time. Practical experience of the writer from working in the industries is that to achieve both high customer service and low cost is getting very challenging for companies day by day. The company has to be good in measuring performance and cost to be able to get it they work with the right things in their aim to be more efficient and effective within Supply Chain Management. They also need a good tool or method to evaluate how efficient and effective the supply chain is.

This research aim can be refined as specific into the following objectives:

- To develop a mathematical model of defective goods supply chain network cost optimization considering both with and without the rework of defectives with all relevant costs from all concerning points" subjected to different variables, cost parameters and constraints.
- To optimize this developed cost model by determining the economic production quantity (EPQ), the quantities of defective products, scrap products and retailer shortages by using GAs and LINPROG solver.
- Evaluate the proposed integrated applications and methodology against two real world test cases as a real industrial application.

The possible outcome of this study will present a comprehensive defective goods supply chain cost optimization model to help the manufacturers faced with problems with defective goods in making decisions. It is regarding not only the cost minimization of production, holding, transportation, defective products, scrap products and retailer shortages but also determines the economic production quantity (EPQ).

This study has a theoretical as well as a practical relevance. To aid the manufacturers in specific decision making a specific study of existing supply chains considering rework of imperfect goods is needed. Starting with the theoretical part is an important task for this study that contributes to more specific knowledge extraction of what areas of the SCM literature that are actually applied and performed in practical. This will make more directed and focused research in this area possible by detecting hidden interrelationship, identifying more detail properties and characteristics and discovering the more specific structure in order to support managers in their decision making. Based upon what actually is done in existing supply chains, this study will suggest more narrowed research areas that are worth more focus and attention in the future.

Moreover, this will also contribute to a better understanding of suitable theoretical starting points for future research.

1.4 Research Methodology

In addressing the research questions, a multi-method approach is adopted for this study that combines quantitative and qualitative research. Quantitative research makes use of numerical data and seeks to identify findings that can be generalized to the world at large. In contrast, qualitative research is typically non-numerical and concerned with an in-depth understanding of phenomena within specific contexts. According to Johnson, Onwuegbuzie, and Turner [9], combining quantitative and qualitative research into multi-method strategies often provides a greater understanding of the phenomena being studied and increases confidence in the generated results.

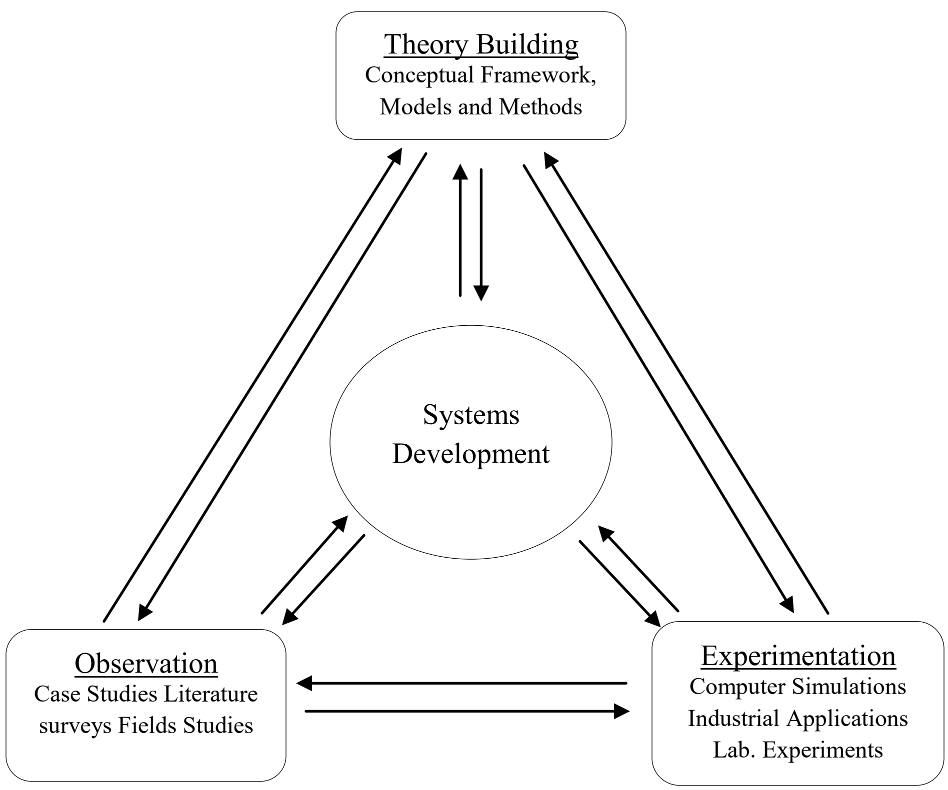

Figure 1.1: A multi methodological research approach.

The overall methodical framework of this thesis is based on the multi-methodical approach is proposed by Nunamaker, Chen, and Purdin [10] which consists of four main building blocks, namely observation, theory building, experimentation and system development. Following the research approach as shown in Figure 1.2, a comprehensive study regarding the existing supply chain optimization approaches is conducted in the early phases of this work. The outcome of this study subsequently generated new ideas and concepts that will help the managers. They point out that the theory building activity is the seedbed from which research objectives and hypothesis may emerge as well as assist in guiding the design of experiments and conduct systematic observations [10]. Hence, the theory building activity has revealed the necessity of developing the mathematical model and supply chain methodology as well as guided the selection of suitable real world problems. The experimentation activity bridges the gap between the in-depth theoretical concepts and observations as it concerns itself with validating the underlying theories through the cases studies [10]. On the other hand, system development implements new technological tools and applications in order to test, measure and validate the underlying theories and concepts to demonstrate their feasibility and applicability, which for the current research has been executed through the DGSCN cost optimization and real-life factory implementation. An overview of the specific methods adopted in this study is presented below for the respective research objective.

This study has been performed within the vast subject Supply Chain Management. To narrow the platform an action research is carried out to improve the method and approach to present the ways of measuring cost of defective goods supply chain. The researcher was engaged in the organization and that particular job of the organization highly motivated the researcher to search for the way to optimize the supply chain efficiency and effectiveness of the inbound and outbound logistics. The mathematical model is developed using standard optimization tool to optimize an integrated supply chain network cost considering some parameters significantly affecting the total profitability. The model is composed of some mathematical equations used to determine the numerical values of some decision variables. The research methodology is outlined as follows:

1. Data Collection: Both primary and secondary data collection techniques are used in this study in order to get quantitative and qualitative information for analysis with an aim of strengthening the content of the entire work. To get the primary data, working process observation and interview with the company staffs and management have been done. Several meetings with different functions were set to get all related information. The secondary data sources are used including relevant published journal articles, published books and company websites. Searches for books and articles have been performed in department library and different databases like Science Direct, Springer Link, Scientia Iranica etc. The following search words have been used: Supply Chain Management, Supply chain, Defective Goods, Performance measurements, Supply Chain Cost, Supply chain efficiency.

Moreover, historical data such as supplier performance, standard working procedure, supplier evaluation, for instance, are used as the secondary data. Also, the quantitative data from the existing working spreadsheets and the company‟s ERP system were accessed and collected.

2. Theoretical Framework and Modeling: An objective function has been structured to minimize the total cost considering multiple manufacturers with different time period and multiple scenarios in each time period.

A literature review and constructive research of existing, related research is conducted to establish a deep understanding of the research area and explore requirements for integrating the defective goods supply chain cost optimization. These are the base to identify the relevance of the embryonic conception with the strengths and weakness of the existing solutions. The findings from this analysis are then used to construct a new methodology for the defective goods supply chain cost optimization. The wide reviews of previous theoretical studies provide more information to make comparison, interpretation and in-depth perception of the primary data which develop the base to generate a theoretical framework of the entire study. Then the objective function has been developed to minimize total cost considering Production cost, Holding cost, Transportation cost, Rework cost, Shortage cost, Discount cost and Service cost, and maximizing demand satisfaction level and volume flexibility considering multiple time period and multiple scenarios in each time period.

3. Constraints Identification: Needful assumptions, limitations, decision variables, cost parameters and constraints are identified. In order to provide a complete description of total cost in supply chains a number of issues (Costs) are dealt with. The current situation of the companies is studied how and why it has happened. Then the involving variables and cause-and-effect relationship were identified, and recommendations were created to improve the process.

4. Data Analysis: After that, the proposed model and methodologies will be illustrated with Primary and Secondary data from two different factories (Steel Factory and Apparel Factory) considering with and without reworking the defectives. After collecting both secondary and primary data, the needful data has been focused, selected, simplified. These raw data received from the company has been analyzed and converted to the desirable form and unit in order to formulate the mathematical models. Finally the desired, interpreted and organized formulation of the model links the theoretical framework with the real world problem that ensures the coherence throughout the entire thesis work.

5. Model Solving: Then the illustrated mathematical model is solved through GAs and LINPROG with various parameters and dimensions. Data analysis methods and knowledge extraction techniques are applied to explore and apply to the dataset to assist decision makers to obtain knowledge about the problem before they make their choices. The methods applied to address the output are experiments and statistical analysis. The collected datasets are then processed and analyzed using statistical methods to draw conclusions.

Industrial relevance of the proposed integrated methods and techniques has been evaluated against two real industrial application studies. Recently, there are several optimization programs available in the market. Each of them provides different advantages and disadvantages. GA has been chosen to apply in this thesis because of its usability and availability. They are quick to implement and the concept is very easy to understand in practice. Moreover, here GA is reasonable to use as this study aims to optimize a single problem a single time.

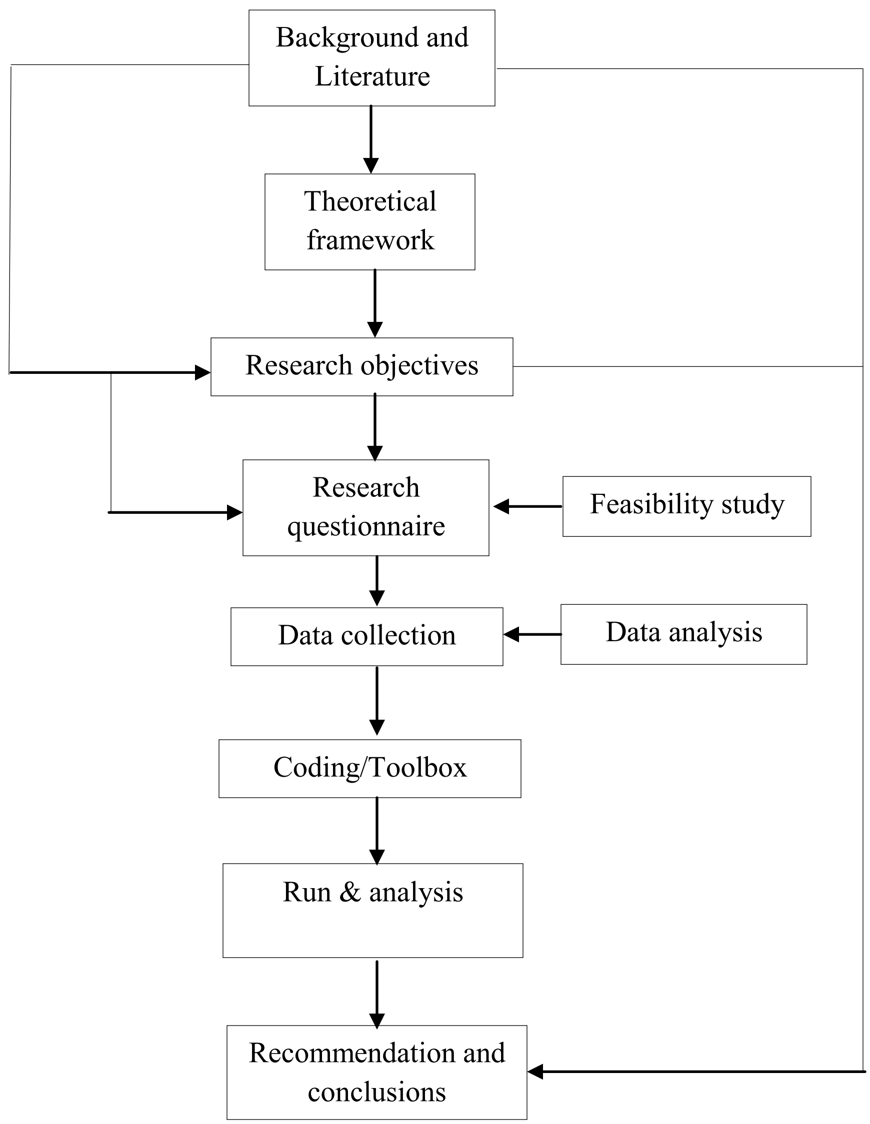

Figure 1.2: Main steps of the study

6. Demonstration and Validation: Finally the output of the GAs will be compared with that of LINPROG to demonstrate and validate the performance of the model by sensitivity analyses. In this entire thesis work two main sources of evidence like interview with the company staffs and management to get all related information and relevant published journal articles, books and company websites are used. To test the work‟s validity this paper provides the citations to all sources where the evidences are collected from. The honorable supervisor has reviewed all of the data and overseen the entire work thoroughly.

The last part of the study is to test the results, draw conclusions and compare the findings with other optimization solver. In the validation approach, the results have been tested by different processes. Subsequently, the result of the model has been compared to different optimization solvers output in order to eliminate all flaws. Consequently, the validity of the model is assured that the models represent the optimal solutions. This part has been based not only on conclusions from the theoretical framework and conclusions from the empirical study, but also on findings and ideas gathered from practical work within the real world problem.

1.5 Thesis Organization

In this section, the structure of the thesis is presented. The thesis is divided into 7 parts where each contains several sections. This thesis is organized as follows as seen in Figure 1.3.

Chapter 1 starts with a background leading to the purpose of this thesis. This section gives the reader the detail background information, problem statement, scopes, aims and techniques of the entire work. This part serves as the introductory information part for the thesis. This chapter discusses the approach and procedure of the study. A short discussion about research design and different steps of the study are described in order to give the reader a good possibility to understand the method applied in the study.

Chapter 2 discusses a comprehensive literature review that provides the incentive of conducting the research presented in this thesis. In this chapter a details review on the literature is delivered which gives a germane idea to the background and gaps in this research area. This provides the main inspiration of this research work.

Research questions are presented and further broken down one by one in this chapter, which is the frame of reference, provides a more thorough explanation of SCM and its organizational and functional scope. The content of SCM, i.e. its fundamental ideas, is thereafter discussed from a functional, professional, and an organizational perspective. The frame of reference is thereafter concluded by a presentation of relevant important aspects within a supply chain to consider when applying the ideas suggested by the SCM literature.

Chapter 3 provides the theoretical background of the problem with several relevant theories for performance measurements which are the base of this thesis. The first section provides the reader a deeper concept of the problem statement regarding the scopes and the expressions of the background. The terms are very broad and a discussion of how they will be used in this thesis is therefore necessary. These details of the concept and optimal analysis are to understand and gain insight to evident any hidden properties of the solutions.

Chapter 4 provides the detail description of the model to measure the efficiency of DGSCN and the solution approaches are discussed. Different assumptions, parameters, variables, objective functions and constraints are explained in this chapter. The model tries to connect separate and dispersed measurements of costs to a common and comprehensive measurement. The model is based on concepts and theories presented earlier in chapter 2 and chapter 3.

Chapter 5 represents the solution techniques that are applied to solve this model. In this part the constructed model has been solved against two real industrial application studies by using Genetic Algorithms and the results are analyzed. It is discussed how it can be measured on different levels of the organization, for products, for plants, for business units etc.

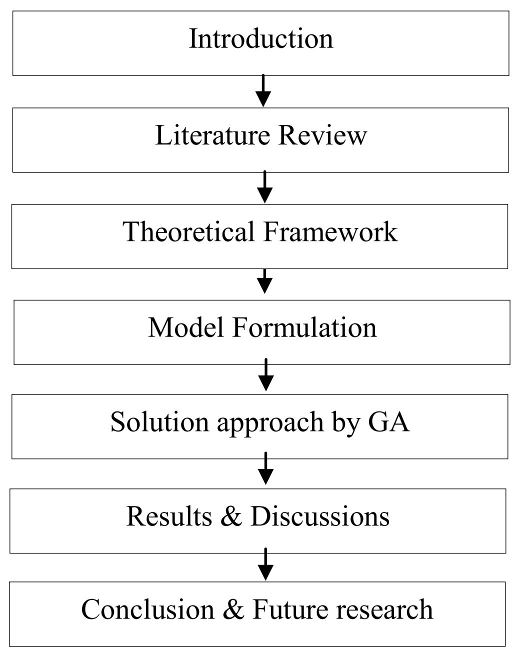

Figure 1.3: Thesis Structure

Chapter 6 is the most crucial part if this study. This part discusses and analyzes the results obtained for two application studies of the model formulated in Chapter 4 through the solution approach chosen in Chapter 5. This Chapter provides sensitivity analyses and links the output of the GAs with that of LINPROG to demonstrate the performance of the model.

Chapter 7 concludes the thesis by wrapping up the main results, providing answers to the research questions, and deriving managerial implications. It consists of the findings from the two previous parts (5 and 6). This Chapter lists the contributions of this research, summarizes the final findings and conclusion with scope of further research. The overall conclusions, contributions to knowledge, and future work that can be extended from this study can be found in Chapter 7.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this section the development of the functional and organizational scope of SCM is described and concludes where the SCM literature stands today concerning these issues. These parts give the reader a picture of how the SCM literature suggests that a focal company should behave in its supply chain to optimize the total cost. Since this thesis has a total cost perspective on SCM, the chapters below are dominated by literature from the field of cost optimization research.

The aim of this chapter is to present a step-by-step guide to facilitate understanding by presenting the critical elements of the literature review process. The point that this study pays attention to about the operational decisions that ultimately covers the context made by strategic and tactical decisions. In order to ensure success of a supply chain management, right decisions about every aspect of a supply chain or supply chain network should be made [11]. Decisions regarding SCN cost optimization are highly concerned with every single part of a chain such as production process, distribution, suppliers and customers and every type of flow and connection between these nodes of the network. Anyway, the current researching on cost optimization is not taking a single perspective, but is including models that are mixing the decision factors for production, quality and time. The reasons behind stands in the needs of the markets and the strategies of the companies, which want to grasp as much value as possible by developing multifunctional networks globally.

However, the interest of this thesis is the modeling of the supply chain problems from a mathematical point of view. Thus, in order to address the cost optimization problem and the wider problem of SCND, several mathematical models are studied for enriching the basic. These models are part of Operations Research, and through the time, researches developed both single and multi-objective ones. However, there is a global recognition that supply chain cost optimization is not a single objective problem, and the models evaluating that should be improved by including different factors and costs regarding Supply Chain.

Economic production quantity (EPQ), imperfect processes, the quantities of defective products, reworks, scrap products and retailer shortages, lead time, customer satisfaction, or quality are some of those factors that can be included in cost optimization models. Regarding the decision problems, academics are sometimes so focused on finding solution methodologies for ideal problems. This suggests that, as it has in other disciplines, an optimization model for supply chain problems can provide a useful connection between research and industry. Different types of supply chain problems found in the literature are discussed in Section 2.3.

2.2 Literature Review Methodology

A literature review is an objective, thorough summary and critical analysis of the relevant available research and research literature on the topic being studied [12]. Its goal is to bring the reader up-to-date with current literature on a topic and form the basis for another goal, such as the justification for future research in that area. To get the current status of research on the topic of total cost optimization of defective goods supply chains, a literature review was performed using the Content Analysis Approach.

Identifying what exactly is of interest and why, is the first step of literature review. It is useful in refining the topic primarily. The method is demonstrated in the Figure 2.1 which helped to organize and structure the core part of the theoretical background literature, starting from the literatures collection, going through the analysis of the literatures, and ending with potential findings from the research.

Literature Collections: Having selected the topic, the next step is to identify the appropriate related information in a structured way. Literature searches are undertaken using computers and electronic databases which offer access to vast quantities of information more easily and quickly than using a manual searches. The collection of potential literatures is performed using search engines like Science Direct, Springer Link, Scientia Iranica etc. In order to identify useful literature the following search words have been used: Supply Chain Management, Supply Chain, Defective Goods, Economic Production Quantity, Reworks, Performance Measurements, Supply Chain Cost, Supply Chain Efficiency, Genetic Algorithm etc. It has been considered alternative keywords with similar meanings to elicit further information regarding the topic.

Literature Abstract Analysis: Appropriate literatures have been gathered at this point of the process. Initially, it is refined the articles that have collected in order to get a sense of what they are about. The filtering of the material found is performed by the summary or abstract at the beginning of the paper, which helps with this process and enables the decision as to whether it is worthy of further reading or inclusion according to the filtering criteria.

Literature Content Synthesis: Once the initial overview has been completed it is undertaken a more systematic and critical review of the content as a second-step for filtering the material. It is referred to as Preview, Question, Read and Summarize which kept staying focused and consistent. It ultimately facilitates easy identification and retrieval of material particularly in a large number of publications. Special attention is set on the problem definitions and model developments, as well as on the specific outcomes of the empirical tests for answering the research questions set in the journals. A very important step in order to understand what researches are currently doing, what are they having in common, and how original are their approaches. However, at this phase there is one sub-step aiming at identification of additional material based on cross-referencing for further relevant publications. Some papers have been discarded at this point which are stored to retrieve at a later stage. It has also served a good basis for the writing of the review.

Literature Evaluation: This step is the most important one for the specific findings of the literature. After having a good insight in the literature that is significant for the research, a material evaluation was performed. This means that several important categories are used to analyze the content of the literature, and a classification of every paper is placed in a predefined matrix. The matrix contains the following structural dimensions: Supply Chain Type, Type of Costs, Defective Goods, Reworking, Discounts, Modeling Techniques, Solution Method, and Demonstration & Validation Type.

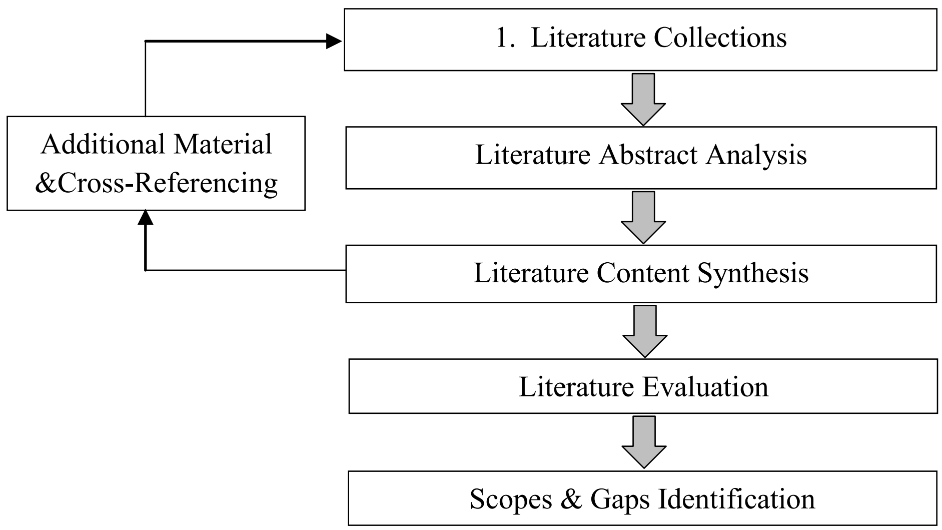

Figure 2.1: Literature Review Methodology

Research Scopes & Gaps Identification: After careful evaluation of the current literature available, key research areas have been spotted. These areas are further narrowed down and then gaps are identified. Performance parameters considered, their combination, application areas, and solution techniques are given priority.

Writing the Review: Once the appraisal of the literature is completed, demonstration of the knowledge in a clear and consistent way has been structured and written. After grouping together the literatures, the varying opinions of different writers on certain topics are compared and contrasted that helped to identify the existing research gaps and inconsistencies. The generated conceptual framework is then presented logically. It definitely provides the reader with a comprehensive background for understanding current knowledge and highlighting the significance of new research. Finally the review is concluded with a concise summary of the findings that describes current knowledge and offers a rationale for conducting future research questions and hypotheses.

2.3 Literature Review

The term Supply Chain Management came up around 1980 by the Boston Consulting Group, but came in focus in the beginning of 1990. It has been said that there is a lack of a clear definition of SCM and the term has developed over time in the literature or practical use. There is a valuable contribution to the understanding of SCM when they argue that a reason for the confusion and many definitions of SCM is that authors try to include two different things within the same definition [13]. In order to sort out the somewhat unclear definition, they distinguish between SCM as a management philosophy on the one hand, and the actions undertaken to realize the philosophy on the other. It is suggested that the management philosophy, called supply chain orientation (SCO), is a prerequisite for SCM. SCO is defined as "the recognition by an organization of the systemic, strategic implications of the tactical activities involved in managing the various flows in a supply chain." SCM in turn, is defined as "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole."

Research regarding supply chain optimization has been performed for a long time. However, it is only in the last decade that the research community has started to investigate defective goods supply chain costs problems. Earlier, Rahman and Sarker formulated a nonlinear cost function to include the costs of inventories, ordering, shipping and deliveries for a manufacturing system where raw materials enter into the assembly line from two different channels. In order to find the best integer solutions to the variables, they proposed an algorithm that uses the branch and bound concept that finds an optimal solution. Later, a simple and better heuristic algorithm is presented that provides better solutions with a lower number of evaluations than Rahman and Sarker"s algorithm [14].

In general, supply chains are complex networks composed of autonomous entities where multiple costs at different levels are in conflict with each other; have to be taken into account. Hence, due to the multiple costs, supply chain decision making is much more complex than treating it as a single objective optimization problem. To optimize the total cost of the entire supply chain it is definitely not enough to optimize these individual drivers separately. Objective functions capturing these drivers have to be optimized simultaneously [15]. The supply chain is an integrated system or network which synchronizes a series of inter-related business processes in order to acquire raw materials (RM), add value to the RM by transforming them into finished goods, distribute and sell to retailers or customers, facilitate the flow of goods, cash and information among the various entities. There is another mathematical expressions corrected and the appropriate solution to the numerical example by Cárdenas-Barrón [16]. They establish the closed forms for the optimal total inventory cost, the conditions for which there is an optimal solution, and the mathematical expressions for determining the total additional cost for working with a non-optimal solution for both policies.

Today the most important concern of the managers is to make their firms viable in the competitive trade world. Managers are looking for effective tools for decision making in the complex business world. A new mathematical model is presented for strategic and tactical planning in a multiple-echelon, multiple-commodity production–distribution network by Bashiri, Badri & Talebi [17]. Different time resolutions are considered for strategic and tactical decisions. Results show that in small and medium scale of instances, high quality solutions can be obtained using CPLEX solver, but for larger instances, some heuristics has to be designed to reduce solution time. Cárdenas-Barrón & Treviño-Garza [18] develop a more general mathematical model and show that all instances can easily be solved optimally by any integer linear programming solver.

Even though these types of optimization problems are the basic research topics, and are the most used ones, the real world problems are not so deterministic and static. All the cost problems in SCM and SCND require models that are tackling uncertainties. Moreover, having the fact that SCND is a big investment for a company, adopting decision-making based on cost optimization problems. Then researchers consider a single-echelon inventory installation under the classical EOQ (with backorders) paradigm to study the effects of supply quality on cost performance [19]. Previous research on imperfect supply quality has focused on variants of the proportional (deterministic or random) yield problem, where supply batches are all accepted and then used, after screening any defects. Here the researchers study an alternative setting where, entire supply batches may be defective (below quality standards) and therefore rejected on arrival.

Total cost optimization problems, as already mentioned before, try to model and solve SCND problems with more than one cost. These costs are usually conflicting between each other. A good problem of this type is defined by more than one cost function, set of constrains, and a technique for obtaining solutions. Regarding this, an algebraic approach is proposed by substituting the use of differential calculus on the system cost function [20]. Researchers derive the optimal common cycle time that minimizes total production, inventory and delivery costs for a multi-item economic production quantity (EPQ) model with scrap and rework.

Now-a-days Information Technology (IT) has become one of the important aspects in the supply chain. Recently, Singh & Teng [21] studied how to enhance supply chain outcomes through IT. To study this phenomenon, they have focused on one or some of these five salient factors: Information Technology Integration (IT), Inter-organizational Trust (TR), Relational Governance (RG), Transaction Cost (TC) and Supply Chain Performance (PE). They develop a research model that includes all these five factors by synthesizing and integrating theoretical perspectives.

However, most of the model is built on an unrealistic assumption that all the produced items need to be of perfect quality. Also, the introduction of work in process (WIP), as part of the inventory has been of lesser concern in developing models. Researchers attempt to develop the economic production quantity considering WIP and imperfect manufacturing process [22]. But the vendor invests money in order to improve the production process and reduce the number of defectives. Another model by Dey & Giri [8] investigates a single-vendor single-buyer integrated production-inventory model with imperfect products. It is observed that, the higher the defect rate, the more beneficial the investment. Numerical studies further explore that an increased demand requires an increased investment to optimize the total cost.

In another study, H. J. Lin [23] investigates a continuous review inventory model involving controllable lead time and a random number of defective goods in buyer‟s arriving order lot. Moreover, they analyze the effects of increasing investment to reduce the lost sales rate when the order quantity, reorder point, lost sales rate and lead time are treated as decision variables.

Another noted economic order quantity model with imperfect quality items is developed [24]. This study considers inspection errors (Type I and a Type II error), shortage backordering and sales returns. If shortages are not allowed, they adopt the order overlapping scheme to develop an EOQ model to prevent shortages during the screening process. An economic production quantity (EPQ) model is also developed for the case where the production process and inspection are both not perfect [25]. Two errors can happen in this stage: Type 1 and Type 2 errors. If a lot is rejected, it goes through a more expensive non-destructive screening stage to segregate items into no defective, re-workable and salvage. Regarding this, an EPQ inventory model is developed for a multiproduct single machine lot-sizing problem with non-conforming items including scrap and rework [26]. In this inventory model, shortage is allowed and is backordered.

Supply-chain management and distribution networks design have attracted the attention of many researchers during recent years. Satisfying the customer demands on time will lead to cost reductions, and will also increase the service level of a chain. A model is developed by Farahani & Elahipanah for just-in-time (JIT) distribution to minimize the costs and surplus products [27]. Delivery lead times, capacity constraints are considered in a multi-period, multi-product and multi-channel network. With an aim to resolve the problem of the increasing costs, integrates purchase, production and sale plans with logistics plans used JIT [28]. It shows that three-stage integrated supply chain planning model can optimize and reduce the costs of supply chain for manufacturing firms very well. A reported model is also proposed using Just-in-time logistics of a defective goods supply chain network by Ghasimi, Ramli & Saibani [29]. They consider all imperfect-quality products are not repairable. Though some important costs are not addressed comprehensively here by researchers, the presented model involves majority of supply chain cost parameters such as transportation cost, inventory holding cost, shortage cost, material handling cost, production cost etc.

In corporate planning, financial decisions may strongly interact with the supply chain planning. In fact, structuring and managing a supply chain is often just part of a whole set of activities associated with a company. Researchers study an imperfect, multi-product production system with rework to minimize the joint total cost of the system, subject to service level and budget constraints [30]. The sensitivity analyses are provided that gives managerial insights to investigate the interdependency of the parameters. Again, a model by Wahab & Jaber [31] shows that the lot size with different holding costs for good and defective items increases when the percentage of defective increases. When there is learning effects, the lot size with different holding costs for the good and defective items is more than the one with same holding costs for the good and defective items.

Most of the studies in the issue of models with imperfect quality assumed the defectives could be sold in a batch by the end of the inspection process and the manufacturing systems were push systems. However, the above assumptions may not be true in the pull system in which buyer is powerful. Therefore, researchers develop a model for items with imperfect quality and quantity discounts where buyer has exerted power over its supplier [32]. Based on the concept of powerful buyer, there are some considerations included in this model. Unlike the traditional integrated supplier–buyer coordination model, T. Y. Lin [33] incorporates overlapped delivery and imperfect items into the production–distribution model. This model improves the observable fact that the system might experience shortage during the screening duration and also takes quantity discount into account. Concerning this, a study proposes an EPQ model for deteriorating/imperfect items with rework process [34]. The imperfect quality items are reworked to become serviceable. At the same time, the remaining good quality items may deteriorate. The inspection of deteriorated items is also imperfect, so that deteriorated items may be sold to customers, which will create negative impact on corporate image.

With an aim to resolve the problem, the researchers extends the traditional EPQ/EOQ model by accounting for imperfect quality items with an example of electronics industry [35]. Items of imperfect quality; not necessarily defective; could be used in another production/inventory situation, that is, less restrictive process and acceptance control. There is a simple approach for determining the economic production quantity for an item with imperfect quality by Suresh Kumar Goyal [36]. They compare the results based on the simple approach with the optimal method for determining the lot size and show that almost optimal results are obtained using the simple approach. Determining an optimal batch quantity in a production system that produces defective items has been the primary focus recently among the researchers. While most of the work has been reported to explore the traditional optimal inventory level in ideal cases, little appears to have been done with rework option. Researchers develop another model to determine the optimum batch quantity in a single-stage system considering rework to minimize the total system cost [37].

Generally, the manufacturing process is „in-control" state at the starting of the production and produced items are of conforming quality. In long-run process, the process shifts from the „in control" state to the „out of control" state after certain time due to higher production rate and production runtime. A study investigates an Economic Production Lot size (EPL) model in an imperfect production system in which the production facility may shift from an „in-control" state to an „out-of-control" state at any random time [38]. Here, another model proposed by Sarkar & Moon [39] illustrates the relationship between quality improvement, reorder point, and lead time, as affected by backorder rate, in an „out-of-control" state.

In a production system, rework process plays an important role in eliminating waste and effectively controlling the cost of manufacturing. Researchers develop a model for the optimum batch quantity with rework process considering two different operational policies. Policy-1 deals with the rework within the same cycle with no shortage and policy-2 deals with the rework done after N cycles, incurring shortages in each cycle. A Study [40] introduce a Fuzzy Economic Production Quantity (FEPQ) model with defective productions that cannot be repaired. They consider a fuzzy opportunity cost and trapezoidal fuzzy costs under fuzzy production quantity in order to extend the traditional production inventory model to the fuzzy environment. A joint replenishment problem (JRP) is presented to determine the optimal reordering policy for multiple items with defective quantity by Ongkunaruk, Wahab & Chen [41]. The objective is to minimize the total expected cost per unit time. A two-dimensional genetic algorithm (GA) is provided to determine an optimal family cycle length and the reorder frequencies.

Supply chain network (SCN) design is to provide an optimal platform for efficient and effective supply chain management. It is an important and strategic operations management problem in supply chain management, and usually involves multiple and conflicting objectives such as cost, service level, resource utilization, etc. Regarding this, in a study, Altiparmak, Gen, Lin & Paksoy [42] propose a new solution procedure based on genetic algorithms to find the set of Pareto-optimal solutions for multi-objective SCND problem. An experimental study using actual data from a company, which is a producer of plastic products in Turkey, is carried out into two stages. Another study considers a single product with probabilistic demand. A generic mathematical model is developed for a two level supply chain through lot size based discount to achieve supply chain coordination [43]. It accounts total supply chain cost which entails product cost, inventory holding cost, ordering cost and stock-out cost considering the maximum allowable supply chain inventory. Genetic Algorithm (GA) is used for determining the optimum levels of ordering quantity, supply chain savings, and discount percentage to enhance supply chain profit.

Cost remained the major objective in almost every model developed for supply chain network optimization. Production lot sizing models are often used to decide the best lot size to minimize operation cost, inventory cost, and setup cost. Cellular manufacturing analyses mainly address how machines should be grouped and parts be produced. Researchers propose a mathematical programming model following an integrated approach for cell configuration and lot sizing in a dynamic manufacturing environment [44]. The model also considers the impact of lot sizes on product quality. To solve the model for practical purposes, a linear programming embedded genetic algorithm was developed.

One of the recent research works investigates the problem of designing an optimum system which supports strategic and tactical decision levels in supply chain management. Another study by Ghassemi Tari & Hashemi considers a vehicle allocation problem for delivering products from a manufacturing firm to a set of depots [45]. The objective is to assign the proper type and number of vehicle to each depot route to minimize the total transportation costs. Due to the computational complexity of the proposed mathematical model, a priority based genetic algorithm capable of solving the real world size problems is proposed. The results reveal that the proposed algorithm is capable of providing the astonishing solutions with minimal computational effort, comparing with the CPLEX solutions. Researchers attempt to quantify the impact of defects on various system performance measures for a production process with 100% inspection followed by rework [46]. Agnihothri & Kenett investigate the impact of the defect distribution on system performance measures such as yield, production lead time, and work-in-process inventory. They provide management guidelines for short term control decisions such as identifying potential bottlenecks under increased workloads and allocating additional resources to release bottlenecks. In order to meet the long term goal of continuously decreasing defect levels, they propose a budget allocation method for process improvement projects.

As time goes, researchers gained more interest on imperfect system cost optimization and continued to explore different areas in supply chain. A study investigates the finite replenishment inventory models of a single product with imperfect production process [47]. These non-conforming items are rejected or reworked or if they reached to the customer, refunded. Optimum production of the product is suggested to have maximum profit using a gradient based mathematical programming technique for optimization. Some interesting decisions regarding production policy are established. Moreover, another work investigates a production remanufacturing system for a single product over a known finite time horizon to satisfy the constant demand by the perfect items [48]. Remanufacturing unit uses the defective items from production unit and the collected used-products from the customers and later items are remanufactured for reuse as fresh items. The models are formulated for maximum total profit out of the whole system. Genetic Algorithm is developed with selection, crossover and mutation.

Researchers always search for performance measures of supply chain which will provide more realistic understanding of a chain and has application in various industries. For a single product manufacturing system, researcher deals with inventory models that unify the decisions for raw materials and the finished product [49]. Some proportions of nonconforming items are considered where the proportion of defective items is not constant. In most real-life manufacturing settings, reworking of defective items may significantly reduce overall costs. S. W. Chiu, Ting & Chiu study the optimal lot sizing decision for a production system with rework, a random scrap rate and a service level constraint [50]. It shows that the expected overall costs of such a production system with backlogging permitted is less than or equal to that of the same model without backlogging.

Defective items should be treated as a result of imperfect quality production. Moreover, most of the classical inventory models usually assume the available warehouse has unlimited capacity. In many practical situations, there exist many factors like temporary price discounts making retailers buy a capacity of goods exceeding their own warehouse. In this case, the researchers study that retailers may rent other warehouses for the need of business [51]. A lot of researchers studied inventory models with two warehouses and inventory models with imperfect quality separately. Considering machine operation time and distribution operation time as uncertain parameters, the objective was to minimize the overall production, distribution, inventory holding and shortage costs.

In many cases, rework is described as the transformation of production rejects into re-usable products of the same or lower quality. Rework can be very profitable, especially if disposal costs are high and if materials are expensive and limited in availability. Furthermore, rework can contribute to a „green image". Such situations occur, for example, in the food industry. Another study deals with the above in a production line considering a single product and that uses the same facilities for production and rework [52]. Result shows that re-workable defective lots deteriorate over time, which effects the rework time and the rework cost. The fundamental assumption of an EOQ model is that 100% of items in an ordered lot are perfect. This assumption is not always pertinent for production processes because of process deterioration or other factors. An EOQ model is developed by Eroglu & Ozdemir for that each ordered lot contains some defective items and shortages backordered [53]. The study shows that defective and useless goods could reduce the overall profits.

Many researchers approach supply chain as an integrated multi-objective supply chain model in simultaneous strategic and operational planning. Multi-objective decision analysis is adopted to allow use of a performance measurement system that includes cost, customer service levels (fill rates), and flexibility (volume or delivery). Many companies struggle with justifying the cost of quality within their supply chain. Outsourcing suppliers to countries such as China has become popular in recent years due to the fact it appears to be more profitable. Regarding this, researchers propose a multi-objective model for the supply chain to evaluate the relationship between profit and quality [54]. They propose a two-objective stochastic model that uses Six Sigma measures to evaluate financial risk. The first objective was to maximize the profit, and the second was to minimize the defective raw material. The numerical results show that a decrement in the defective raw material led to an increment in the profit and a decrease in the financial risk. Jung & Jeong discuss the conflict between different units in a Supply chain [55]. They say that each unit tries to minimize its own cost and is not considering the whole supply chain. An improvement in production that gives a lower production price is positive for the company. The installation cost might increase more than the decrease in production and the total effect for the supply chain is negative.

In recent decades, the lean methodology, and the development of its principles and concepts have widely been applied in SCM. One of the most important strategies of being lean is having efficient inventory within the chain. Amirjabbari & Bhuiyan apply a safety stock cost minimization model in a manufacturing company [56]. The model results in optimum levels and locations of safety stock within the company"s supply chain in order to minimize total logistics costs. Most often, limited information is available on the risk of defective instruments. These instruments may be dangerous on many cases. The malfunctioning of surgical instruments may lead to serious medical accidents. Researchers study the features of defective surgical instruments to establish a strategy to reduce the risk of medical accidents [57].

Historically, researchers have focused relatively early on the design of production systems. Typically, profit maximization models were proposed but those still had a limited scope and are not able to deal with many realistic supply chain requirements. To be successful in the long term it is necessary to fulfill or exceed customer‟s expectations. SCM thinking has been influenced by theories like systems theory, economics, game-theory, inter organizational relationships and industrial network theories. And it has become now a very rich but still heterogeneous academic field. Recent literature reviews try to address the heterogeneity by suggesting frameworks to better organize all the different approaches and concepts. Researchers explicitly integrate the inspection time into the economic production model with rework, and demonstrate the significant effect that the inspection time has on the results [58]. The expected profit functions are developed using the renewal reward theory, and closed form expressions for the optimal production lot size are derived.

Most of the previous approaches usually include the separate solution of the master planning, transportation and distribution cost problems. Now-a-days different integrated supply chain cost optimization models can be found to determine the actions across the whole supply chain. Imperfect product is one of the important challenges that companies are facing now. Several studies have been undertaken where the SC cost problems have been optimized and the results are more than encouraging. Objectives considered were, minimizing system wide costs and maximizing customer satisfaction. A bi-objective model was proposed that minimizes system wide costs of the supply chain and delays on delivery of products to distribution centers for a three echelon supply chain [59]. Key to success of any business is satisfying customer's demands on time which may result in cost reductions and increase in service level. If poor decisions are made, they may lead to excess inventories that are costly or to insufficient inventory that cannot meet customer's demands. In addition to the above genetic algorithm based supply chain models, several other models have also been proposed in particular based on the swarm-based optimized models. Ant colony optimization techniques are also used in many cases to find the best combination of the resource options by minimizing the total cost and the total lead time.

2.4 Literature Summary

Literature review is analytic and critical of what has been written, identifies areas of controversy, and raises questions and areas which need further research. It is crucial to group together, compare, contrast and summarize the varying opinions of different writers on certain topics.

Supply chain management is a vast area as discussed above in literature and there are a lot of works have been done regarding supply chain cost optimization. Most of the proposed classical production models presume that all goods produced by manufacturer are perfect in quality. But, in practical, production of defective goods is quite inevitable and is very relevant from a practitioner‟s perspective. So, the effects of these defective goods need more focus by the researchers as an essential concern in cost optimization.

Most of the proposed models are developed over a single stage SC horizon while some researchers considered a multi staged SC planning approach. Maximization of the chain profit, as a single objective, is often the objective function of most of the proposed models. Most of the researchers are interested to maximize of the supply chain profit to a greater extent as well. Less attention has been focused on minimizing of total cost considering multi staged supply chain as a whole. In case of defective goods supply chain cost optimization which is very few in number compared to the ordinary cost optimization models, most of them considered single stage cost of a chain. Few researchers used production costs along with transportation, holding and delivery costs etc. as second objective along with cost or profit. Most of these models deal with single objective. There are very few models which incorporated more than two objectives regarding cost and quality concern. Moreover, both quantitative and qualitative performance measures in addressing multi staged SC cost optimization problems are ignored.

Due to its impacts on economic order quantity, several models have been developed for defective goods supply chain. These models show that defective goods and shortages might reduce the overall profit of the firm. Based on the result of reviewed literatures, most of the models consider only two or three costs, which are mainly production, transportation and holding cost. This is a considerable drawback of the existing models, though these are the most important source of costs, other sources of costs such as rework, discount, shortage and services greatly influence the SC efficiency, which triggers the need for jointly considering them.

From the discussions above, it is clear that defective goods derive mainly from sudden events and the unsatisfactory performance of manufacturers. Most of the sudden events are either uncontrollable or very difficult to predict. Although firms do have some choices to reduce possible loss, it is almost impossible for them to eliminate the defectives fully. At the same time, most of the defectives caused by the unsatisfactory performance of manufacturers are controllable, and some of them can even be eliminated. By choosing the best optimal way through the whole chain, this type of loss can be minimized.

Another regularly concerned model is economic batch quantity optimization model for defective goods. Here, most of the researchers did not consider the reworking function of defective goods as these items may be sold at discount. But sometimes reworking of defective goods can be quite profitable if the cost of production is high, raw materials are limited or finished goods are costly. For such supply chain optimization and search problems, Genetic Algorithms (GAs), which are easy to implement in practice, have been frequently used to generate useful optimum solutions.

However, real-world cases usually are not that simple. Though its average defective rate may be lower than that of the others, the process with the best performance may charge more for its on-time production. Now the question is how the decisions should be made in such multi-criteria optimization problem. Firms need mathematical models to make such difficult decisions regarding the EPQ, and other costs and parameters along with times. Hence there is a gap of works particularly in defective goods supply chain cost optimization. In other words, there need to develop some mathematical models and tools to help firms making decisions on process selection, production quantity, transportation, holding, reworks etc. into consideration.

In order to find the ways for increasing the flow and achieving better efficiency in the current competitive global markets, practitioners have been continuously forced to make the appropriate decision regarding cost, quality and time. But these factors are not fully concerned in a single model. Expected attentions have not been focused in this particular area as per current situation. There is a time demand to develop a single mathematical model that can contribute to the practitioners providing a clearer picture of possible actions and ways to behave. Today for an individual company, it is difficult to understand and judge what to do since the literature most often is too differentiated. It only says that the actors in a supply chain should be optimum in terms of costs, and gives often a gloomy picture as a whole to what part of the literature is of special for a certain manufacturer. So, there is a potential scope for further research in this particular area addressing all these sporadic factors(production, transportation, holding, defective goods, reworks, discounts, scrap products, delivery shortage, time interval and service cost) in a unique mathematical model to ease the manufacturers making the supply chain more efficient.

CHAPTER 3

THEORETICAL BACKGROUND

3.1 Theoretical background & Scope of work

This section describes the relevant definitions, theories and scopes on the Supply Chain Management and Costs that are important for this study. In order to formulate a cost optimization model the relevant theories on SCM and its scopes have to be known. In this chapter a supply chain from a general perspective as well as the management of it is described. The approaches being discussed include how a supply chain cost should be optimized in order to be considered the most efficient to get the optimum results.

The large amount of research in the SCM area has led to a wide range of definitions, expressions and concepts and it is therefore necessary to discuss the expressions supply chain management, logistics management and the scopes of cost optimization in order to further specify and describe the focus of this thesis. Thereafter different cost and its connection to SCM are discussed.

3.1.1 Supply chain

Currently a lot of definitions of a Supply chain exist. Different people define the term "Supply Chain" in different ways. A company‟s Supply chain is defined by Christopher [4] as "the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hand of the ultimate customer." Many aspects of supply chain may be discussed. Some discussed aspects are: the number of companies involved in the chain, Supply chain vs. Demand chain, chain perspective versus the own company and which parts of a company are involved in the Supply chain.

As a new way of doing business, however, a growing number of firms have begun to realize the strategic importance of planning, controlling and designing a supply chain as a whole [60]. According to certain definitions of Supply chains there has to be more than one company involved in the chain in order for it to be defined as a Supply chain. Supply chain comprises geographically dispersed facilities where raw material, intermediate or finished products are acquired, transformed, stored or sold and transportation links that connect facilities along with products flow. The facilities can be operated by the own company or by vendors, customers, third party providers or with other companies with which the company has business arrangements. The definition supply chain may not be depending on the number of companies involved in the chain, but rather on what functions are involved.

To be able to discuss SCM and total cost it is very important to define the common functions of the company that should be considered to be a part of the Supply chain. Common functions in a company are: Research and Development, Marketing and Sales, Supply, Service, General administration and business controlling. Hence, supply chain integration is not a one-time accomplishment. In order to sustain supply chain integration, supply chain wide performance measurement system is needed [61]. Research and Development (R&D) is the function of the company in which products are developed. The ways the products are developed have a deep impact on the supply. Thus, it is very important with a close co-operation between R&D and supply to get the lowest possible cost. For example, if the product developers develop a product in different variants that the customer can choose from, this has the effect of a higher supply cost in the end. More variants of products in stock gives more inventory cost.

What is contained within the function marketing and sales differs between different companies. This function includes the people who are out selling the product and all activities related to marketing. Marketing activities may include commercials in newspapers, events and so on.

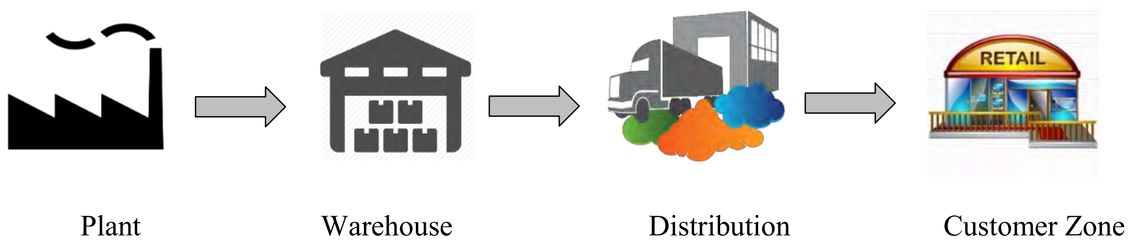

Figure 3.1: Supply chain echelons

The Supply function includes inbound logistics, outbound logistics, sourcing, production and distribution. Inbound logistics is taking care of material flows going into the company and outbound is taking care of material flows going out from the company. Sourcing is responsible for contract agreements with the suppliers of material. Service is the function of the company taking care of after sales activities. This means that they take care of selling spare parts and providing technical support after the end of warranty period of the product.

General administration and business controlling is the function within the company taking care of activities that cannot be related to the other four parts. The general management is part of this. Business controlling and other administrative support functions are also a part of this if they cannot be related to any of the other. Out of these five functions of a company, Supply is part of the supply chain, but also parts of the other functions may be included in the scope of the supply chain.

3.1.2 Supply Chain Management

The term Supply Chain Management (SCM) was initially coined in the early 1980s by consultants. As there are many different definitions of supply chain and supply chain management, there is nevertheless no consensus as to the exact meaning of SCM. For the purpose of this study, the definition of Mentzer et al. [13] has been chosen, who define SCM as "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole". The following figure shows the supply chain triangle, which is describing the conflict between cost and performance [62]. The main objective for a company is to provide service to the final customer, but at the same time minimize the costs. This study aims to develop a cost minimization model using GAs according to different variables, cost parameters and constraints made by the case company. The supply chain triangle is proposed by Schary and Skøjtt-Larsen as the following Figure 3.2.

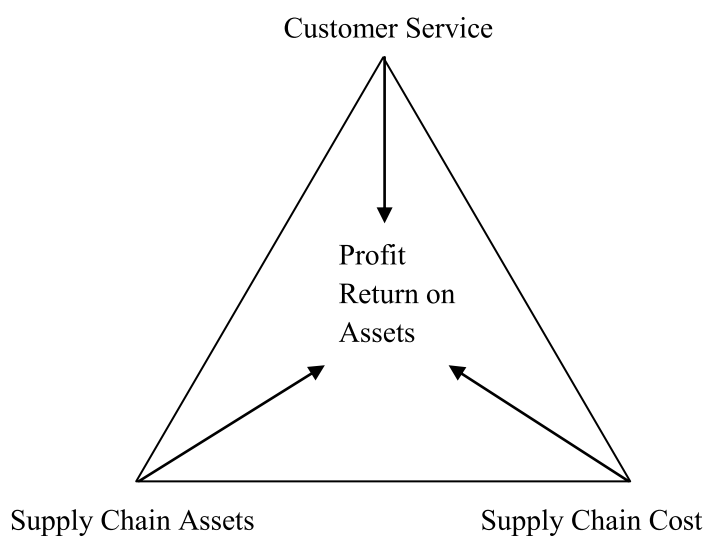

Figure 3.2: The Supply chain Triangle

Supply Chain Management is described as the integration of control and planning of materials and products flow from supplier to customer [63]. Probably one reason for this plethora of definitions is that so many different disciplines have contributed to SCM such as logistics and transportation, operations management, materials and distribution management, marketing, purchasing and information technology [64]. There are three reasons for companies to engage in SCM [65]. The reasons are to reduce inventory holding cost, increase customer service and increase competiveness of the Supply chain.

Supply chain management is an activity to optimize material and information flows along the chain with the purpose of meeting the customer demand. The aim of SCM is extending the logistics upstream to the suppliers as well as downstream to final customers to gain the highest profit and spend the lowest cost [66]. The basis of SCM philosophy is the integration of all function units in the market channel. The link between the market and supply chain can be expressed as the following Figure 3.3.

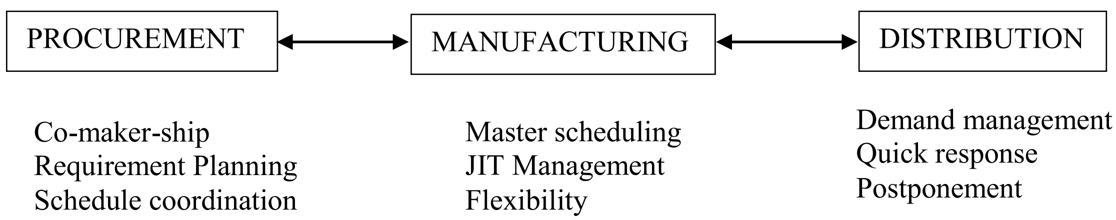

Figure 3.3: Critical linkage in supply chain

Normally, procurement strategies have been made to reduce cost of material which is the biggest proportion of the total cost. However, procurement decisions and procedures are not only influenced by the cost, but also the innovation and lead time. Traditional perception of manufacturing increases non-production cost in the factory such as inventory cost and facilities investment. Therefore Lean philosophy has been used in manufacturing processes for decades to eliminate waste of which associated cost would be reduced. Transport and warehousing were previously perceived as parts of supply distribution. However, distribution is an information-based, valued-added activity which links the marketplace and the factory together. For a successful company, the substantial task of distribution is demand management which is the process of anticipating and fulfilling orders against defined customer service goals.

3.1.3 Supply Chain Management and Logistics Management

In many cases researchers write that the terms SCM and Logistics management are used as synonyms. The scope of logistics spans the organization from the management of raw materials, through to the delivery of the final product [4]. The mission of logistics management is to plan and co-ordinate all those activities necessary to achieve decision levels of delivered service and quality at lowest possible cost [4]. SCM is an extension of Logistics management. Logistics management is primarily concerned with optimization of flows within the organization while SCM wider external. The concept SCM has been derived from logistics management. Logistics is that part of the Supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from the point of origin to the point of consumption in order to meet customer‟s requirements [67].

The relationship between SCM and Logistics management is however not always easily understood and different opinions exist about what they actually encompass. Sometimes SCM and Logistics management are interpreted in the same way and are therefore often used interchangeably in literature. With results from a survey as a basis, researchers highlight the different understandings of the terms among logistics and SCM experts in the United States [6]. The survey shows four different views on how to interpret the functional scope of SCM vs. logistics, Figure 3.4. The four figures represent four different ways to interpret the scope of the two expressions relative to each other. However, other ways to distinguish them can also be found in the literature. One often mentioned difference according to literature is whether they are occupied with internal or external issues. Some researchers [4] argues that SCM is "no more than an extension of the logic of logistics" and claims that "Logistics management is primarily concerned with optimizing flows within the organization while SCM recognizes that internal integration by itself is not sufficient."

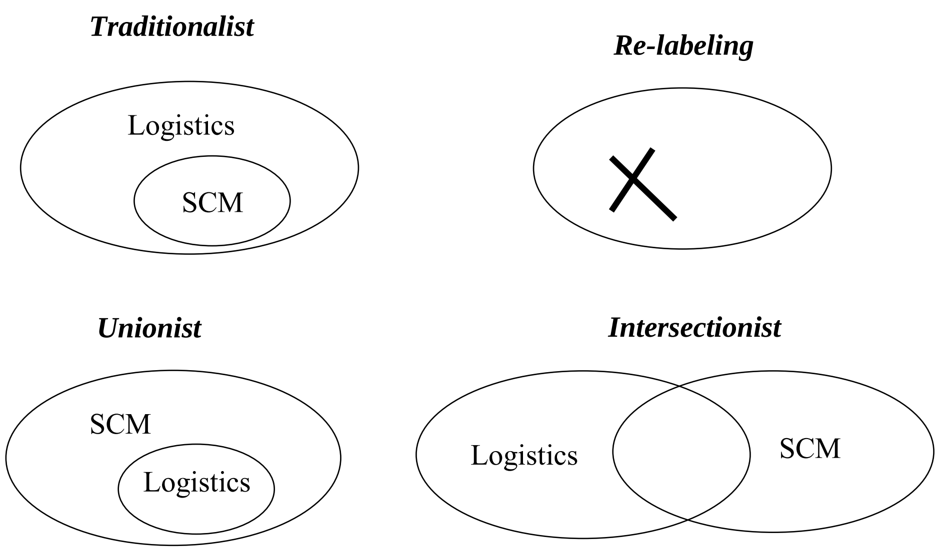

Figure 3.4: Perspectives on Logistics vs. SCM

Considering definitions of SCM and logistics management, the definitions made by the Council of Supply Chain Management Professionals, CSCMP, are one of the most cited sources. In a document on their homepage, SCM is defined as follows: "Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all Logistics Management activities. Importantly, it also included coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, Supply Chain Management integrates supply and demand management within and across companies". *(www.cscmp.org)*.

3.2 The scopes of Supply Chain Management

Why Supply Chain Management? Many companies are discovering that efficient Supply Chain Management is what they need to focus on in order to increase profit and market share. There are companies that have reduced their manufacturing cost as much as is practically possible and then the key issues is SCM. The company has to focus on the whole Supply chain to find new areas where cost can be reduced.

SCM has a wide scope. SCM takes into consideration every facility that has an impact on cost and plays a role in making the product conform to customer requirements. The objective of SCM is to be efficient and cost effective across the entire system. Cost efficiency means consideration of the total system wide costs, from transportation and distribution to inventories of raw materials, work in process and finished goods and that the cost is minimized. Supply Chain Management is not simply about minimizing transportation cost and reducing inventories, but rather on taking a system approach to find improvement areas. The theories within the SCM area are connected to many different areas. SCM should be considered to come from economics, engineering, operation management, production management and logistics.

Supply Chain Effectiveness: The success of supply chains are composed of three different dimensions: customer service, capital employed, total cost [68]. All these three parts are interrelated to each other and the ultimate goal of the total chain is to minimize the total cost. Effectiveness is the level of results from the actions of employees and managers. It is about doing the right task, completing activities and achieving goals. Companies measure effectiveness often by conducting performance reviews. The effectiveness of a workforce has an enormous impact on the quality of a company‟s product or service, which often dictates a company‟s reputation and customer satisfaction along with minimizing the waste.

Effectiveness is defined as the extent to which goals are accomplished while efficiency is the measure of how well the resources expended are utilized [13]. Efficiency in this thesis is used as describing how well a company optimizes the Supply chain to maximize profitability which is discussed later. The overall objective of any supply chain system is to maximize profitability.

Supply Chain Efficiency: Efficiency is about doing the things in an optimal way, for example doing it the fasted or the least expensive way. It could be the wrong thing, but it was done optimally. Efficiency is the measure of how well the measurement of how well the resources expended are utilized [69]. Supply chain efficiency is how well the resources in the Supply chain are utilized. The primary purpose for the efficient Supply chain is to fulfill demand at the lowest possible cost.

Supply Chains should have gained both cost leader ship and service leader ship. The purpose of Supply Chain Management is to support the company to earn as much money as possible. This means as low cost as possible and at the same time sell as much as possible. To remain competitive in the new global environment companies will have to seek ways to lower cost and service enhanced [4]. This means that Supply chain efficiency and effectiveness will become even more critical.

The most comprehensive tradeoff is between customer service and Supply Chain Cost. Improving customer service often means that the total Supply Chain Cost increase. There are optimization models that can assist management in evaluating objectives. The Efficient Frontier [4] is the curve for how the total cost increase with higher service level Figure 3.5. Higher service level means more service for the customer. The service can for example be short order-acknowledge time and high delivery precision.

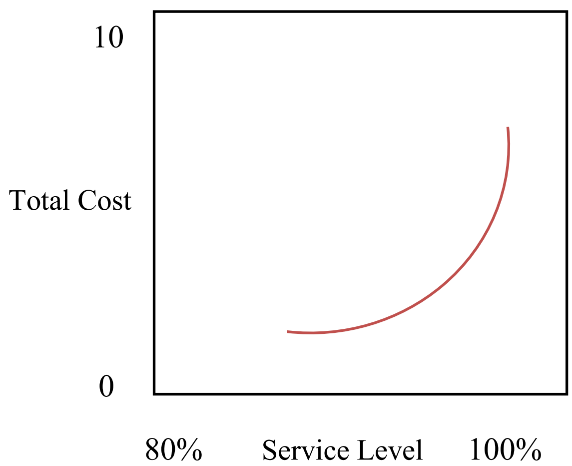

Figure 3.5: The Efficient Frontier

Reliability: Because of more competitive market, every function unit, including customer, in the supply chain has to reduce cost. For example, inventory must be reduced and delivered to the customers on their demand punctually. The company strategy must also emphasis on reliability as a prime objective. Process design and control which are related to information fastness and accuracy are the keys to enhance logistics reliability. Moreover, supply chain management can simplify the process because the process is considered as the whole process rather than fragmented basis. Non-value-adding activities are discovered, then the numbers of hand-offs can be reduced. As a result, there is a possibility to decrease errors in the chain. Six-sigma implementation reduces variations in the process by identifying the cause of variability and using statistical tools to control the process performance.

Responsiveness: Responsiveness is the ability to respond to the customer demand quickly. Quick response logistics is a term of transporting smaller quantities directly to the point of use with in the shorter lead time. The core activity to reduce time is eliminating non-value-adding activities. This implies the number of tasks operated is reduced. Even some cost may increase as a result of eliminating redundant stages; however, the final result is cost effective. Another important key influencing responsiveness of the logistics system is information transparency. If there are some obstacles or difficulties to approach information, time to respond to the real demand will be extended as well.

In contrast, lean production which is developed to reach goal of reducing the cost by eliminating unnecessary non-valued adding activities, lacks speed and flexibility. As a result, there is a need to develop an effective supply chain which is flexible, rapid and cost concern at the same time. The responsive supply chain which is defined as "a network of firms that is capable of creating wealth to its stakeholders in a competitive environment by reacting quickly and cost effectively to changing market requirement" combines all qualities needed.

Resilience: One of the market characteristics is being dynamic, so there are, constantly, risks and uncertainty. Especially in the global supply chain, risks are higher and more difficult to control. Thus, buffers in forms of inventory and excess capacity, for instance, are created in order to absorb risks; however, number of buffers depends on customer service level strategies of the company. Buffers are not made in all nodes but normally only in the critical function units. Besides, audit risk team should be set up to follow up the risk management policies whether all risks are still managed and mitigated.

Relationships: The number of stakeholders also increases due to wider range of product requirement. The relationships within the supply chain have higher importance. Furthermore, logistics management is a thread connecting the inbound and outbound flows. Accordingly, the strong relationships with supplier network can augment the possibility to improve quality, reduce cost, and response quicker. For example, good relationship creates trust between the supplier and the customer, so the real data is shared and the vendor can see customer demand directly to prepare the capacity and replenishment instead of waiting for placed orders. This sort of relationship can be identified as vendor managed inventory. Previously, logistics improvement is not so much concerned because of difficulty in measurement. The system such as ERP allows the supply chain to become truly demand-driven by means of shared information.

3.3 Supply Chain Costs

Researchers study on the ways of handling measurements of SCC varies among 30 companies [62]. The study shows that it is only 3 companies out of 30 that say that they don"t measure SCC at all. The rest is doing some kind of measurement of SCC. The study shows that most of the participating companies have started with the measurement of SCC, but there is still a long way to go to come up to complete measurements of SCC.

Analysis of SCC can be performed in different ways. Different kind of grouping of cost can be found in the literature. SSC is defined as cost components related to Order handling, Purchasing, Manufacturing cost, Cost for stock handling, and Cost for systems needed to handle the Supply. Researchers break down the SCC into five different categories: Transportation cost, Order processing cost, Production setup cost, Inventory cost and Backorder cost [70]. The denomination can differ, but the measurement is the same. SCC as a measurement is more interesting for companies that have to focus on having a total view on the cost in the supply chain to be able to reduce cost.

Table 3.1: Different types of costs

1.Manufacturing Cost:	• Material cost • Test cost • Direct and indirect labor cost • Machine cost
2.Administrative Cost:	• Cost for order handling • Cost for people handling purchasing • Cost for people handling claims • Cost for people that handles support for the Supply chain like secretary, managers and others that support the Supply chain. • Cost for installation if that is applicable.
3.Warehousing Cost:	• Cost for inspection of incoming goods • Cost for people working in the warehouse • Cost for the building
4.Distribution Cost:	• Cost for shipping incoming material if the own company is paying this. • Cost for shipping the material to the customer. • Cost for insurance and inspection of goods if applicable • Cost for Letter of credit if applicable • Cost for customs clearance if applicable
5.Capital Cost:	• Cost for tied up capital in warehouse • Cost for tied up capital during transportation • Cost for tied up capital until the customer has paid the invoice.
6.Installation Cost:	• Cost for people doing the installation • Cost for the buildings. • Cost for Tools and machines.

SCC is suggested to be divided into five main areas and a sixth area that is applicable for supply chains there installation is included. The reason for dividing SCC in these six groups is to clearly see where in the SSC comes from. SCC is concentrating on the costs connected to the supply chain as described above. However this cost in practice can be estimated in different ways and with different accuracy. In some supply chains the production cost is the dominant part. In other supply chain the distribution cost can dominate and in a third there are now warehouse cost and distribution cost. These 6 areas can be seen as the baseline. Each of them can be split into more detailed groups (Table: 3.1).

Shortage costs have different definitions for raw materials, semi-finished parts and finished parts as they are located in different stages within the chain and their shortages have different impacts on the total system. In fact, it‟s the costs of safety stock violation. Shortage of the finished part which is required by assembly causes disruptions and stock not pulled for all the other parts related to that finished part in different locations of the supply chain [71]. In addition, shortage of the finished part causes the finished assembled product to be held up unreleased. Therefore, the shortage cost is defined as follows:

Sh = (Standard cost of the finished assembled product × average days of holding finished assembled product due to the shortage of the specific finished part during last year × 0.1)/365

The coefficient of 10% in the above formula is the annual interest rate that company could receive by putting this amount of money in the bank, although the company currently has this as inventory buckets instead of cash. As can be seen through the formulas and definitions, a period of one year has been selected for historical data collection in order to have a sufficient window view. Besides this direct cost due to shortage, there are many intangible effects of this shortage that are called indirect costs and are difficult to gauge accurately. One of them is loss of customers‟ goodwill that may turn them to other competitors in the future.

Total SCC is the sum of capital cost, installation cost, administrative cost, manufacturing cost, warehouse cost, distribution cost. If total SCC is divided by net sales, the income from the activity of the company, it presents a key figure that shows how large part Total SCC consists of Net sales.

The ratio between total SCC and Net sales is more comparable between different products, plants, markets, companies etc. [62]. However, the best and most sensible comparison is with itself over time, a decrease of the ratio is favorable and an increase should be avoided.

$$\text{SCC} = \frac{Total\ SSC}{Net\ sales}$$

The system is a complicated network of which all function units have interactions. Because of complex network, all costs are quite difficult to reveal as it is known as implicit costs. In general, the total cost is a summation between explicit and implicit costs. Measuring an accurate Supply Chain Cost can be difficult. One reason for the difficulties in measuring SCC is that the set-up of the accounting systems in a company is not adjusted to SCC measurements.

Normally, the optimization purpose is to minimize cost, for example, calculate the minimum cost of inventory to get the required customer service level. All in all, the total cost calculated from integrated activities should be applied to optimize entire system rather than using the calculation from single unit tasks in order to reach strategic decisions. Nevertheless, this process needs to be incorporated and understood; some cost may be increased to shrink the cost of the whole system. Due to the complex relationship of influencing factors affecting on supply chain cost, the management should make a decision on the SCM strategy which can result in many ways. Besides, each parameter should be understood clearly because it effects on the overall performance and cost.

3.4 Operations research

One of the techniques used to aid a decision making is operations research (OR) method. In general, operations research technique is used widely to solve the problems existing in the reality, especially in the operation management. Now-a-days, there are several fields using operations research methods to optimize theirs operations such as manufacturing, transportation, and so forth.

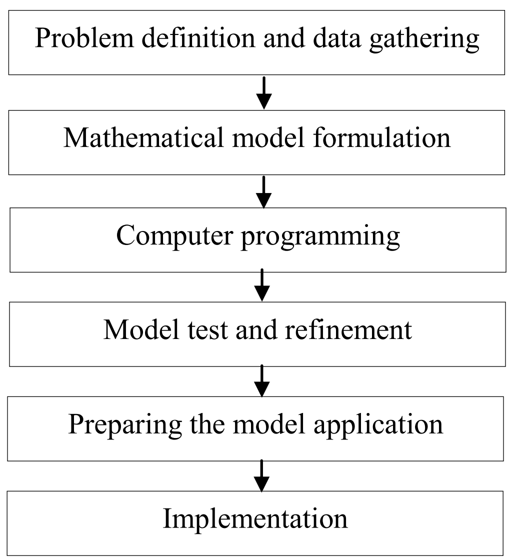

Figure 3.6: Steps of OR

Inventory system and production planning are the most successful areas by obtaining the advantages of the operations research. In addition, there are a lot of techniques used in the operations research, linear programming and integer programming, for instance. Among several techniques, linear programming model is mostly used in production planning because of its simplicity and effectiveness.

The operations research procedure consists of six steps, problem definition and data gathering, mathematical model formulation, computer programming, model test and refinement, preparing the model application, and implementation.

The characteristics of the operations research result in broad applications in various parts. In order to create a model, the problem is studied and all relevant data are gathered, and then the scientific model is formulated to describe it. Generally, mathematical method is used to explain the relationship among several parameters and constraints into equations, consequently the problem becomes tangible. Furthermore, the model must be validated for the real situation by using it in several experiments. In this step, it can be called as model validation. Moreover, the operations research can reduce conflicts which normally happen in a decision making.

The best solution for the whole system is provided by including all interesting parameters into the model. Therefore, an operations research team should be an arrangement of persons from several backgrounds such as mathematics, statistics, computer science, and economics. However, the model ought to be created in the appropriate scope which is not too specific to optimize the whole organization; on the other hand, the model must be particular enough due to convenient use.

CHAPTER 4

MODEL FORMULATION

4.1. Model Formulation

This study proposes a mathematical model for a defective goods supply chain network to aid the decision maker in making decisions regarding to minimize the costs of production, maintenance, transportation, reworks, scrap products and shortages due to the production of defective goods. The model is divided into three main echelons: echelon-1 indicates the manufacturers, echelon-2 represents the distributors and echelon-3 denotes the retailers of the chain. The supply chain network used in this study is shown in Figure: 3.1.

4.1.1. Assumptions and limitations of the study

Some assumptions have been considered while developing this costs optimization model. The main assumptions of the provided model are:

1. Production rate of the manufactures can vary from scenario to scenario.
2. Each product takes same time to be manufactured at each production plant.
3. At the starting of the period the demand was appointed to the manufacturers.
4. Manufacturer shortage is allowed.
5. The inspection process is ideal and the inspection time is not considered.
6. Needful rework of defective goods is allowed when required.
7. The time span of each period is equal to the sum of production times and reworks times.
8. All defective goods may not repairable, while those are counted as scraps goods.
9. Work in progress has no holding costs.
10. The points of plants, distributors, retailers and suppliers are fixed for each scenario.
11. Handling or processing time for a product is same for the same warehouse.
12. Handling or processing time for a product is same for the same distribution center.
13. Fixed infrastructure costs do not depend on scenarios.
14. The structure of the transportation network (i.e. transportation links between plant, warehouse, distribution center, and customer zone) is independent of the scenarios.
15. Transportation time between echelons is independent of the scenarios.
16. The model is developed for multiple manufacturers, distributors, retailers, products and multi-echelons.
17. Different capacities of the manufacturers, the distributors and the retailers are known.
18. At the beginning or end of the horizon the inventory is zero at the distributors.
19. Different indirect costs such as stagnant capital and maintenance are not counted.

Moreover, several limitations were considered in the proposed model:

I. Production time and rework time of the manufacturers are limited.
II. The capacities of the manufacturer, distributor and retailers are limited.
III. Different storage capacities for the perfect and the defective goods are limited.
IV. All demands must be fulfilled during the horizon.

4.1.2. Variables and parameters

The parameters and decision variables used in the cost optimization are defined as follows

Cost Parameter:

1. P_{mnt} = Production cost of each product n by manufacturer m in time t
2. H_{dnt} = Holding cost of each product n by distributor d in time t
3. h_{mnt} = Holding cost of each defective product n by manufacturer m in time t
4. G_{mdnt} = Transportation cost of each products n from manufacturer m to distributor n in time t
5. g_{drnt} = Transportation cost of each product n from distributor d to retailer r in time t
6. z_{mnt} = Transportation cost of each defective n from manufacturer m to storage s in time t
7. p_{mnt} = Percentage of defective goods n produced by manufacturer m in time t
8. a_{mnt} = Time required to produce each product n by manufacturer m in time t
9. b_{mnt} = Rework time required for each defective goods n by manufacturer m in time t
10. Ta_t = Total production time in period t
11. Tb_t = Total rework time in period t
12. R_{mnt} = Rework cost per defective products n by manufacturer m in time t
13. s_{mnt} = Percentage of scrap goods n produced by manufacturer m in time t
14. Sh_{mnt} = Shortage cost of each product n in manufacturer m in time t
15. D_{mnt} = Discount cost of each scrap product n for sale by manufacturer m in time t
16. C_{mnt} = Production capacity of manufacturer m for product n in time t
17. A_{dt} = Total storage capacity of distributor d in time t
18. A_{dnt} = Storage capacity of distributor d for product n in time t
19. B_{rt} = Total storage capacity of retailer r in time t
20. B_{rnt} = Storage capacity of retailer r for product n in time t
21. R_{rnt} = Demand of retailer r of product n in time t
22. Sc_{mnt} = Service cost of each product or service n in manufacturer m in time t.

Variables:

1. q_{mnt} = EPQ of product n by manufacturer m in time t
2. X_{mdnt} = Amount of product n transported from manufacturer m to distributor d in time t
3. d_{mnt} = Amount of defective goods n produced by manufacturer m in time t
4. n_{mnt} = Amount of perfect product n by manufacturer m in time t before rework
5. N_{mnt} = Amount of perfect product n by manufacturer m in time t after rework
6. Y_{drnt} = Amount of product n transported from distributor d to retailer r in time t
7. Sr_{mnt} = Amount of scrap good n by manufacturer m in time
8. Tt_t = Length of the period in time t

4.2 Objective function to optimize the overall expected costs of a defective goods supply chain network

The objective function that minimizes the total costs of the supply chain, including the costs of production, holding at the distributor, defective good storage, rework of defective goods, transportation from the manufacturers to the distributors, transportation from the distributors to the retailers, transportation from the manufacturers to defective good storage and vice versa, the discount cost of scrap goods for sale, manufacturers shortage due to defective goods production and the service cost for providing a service.

4.2.1 Production Cost

The production cost is given by the economic production quantity of the product by manufacturer under particular scenario. The production cost can be presented by the corresponding term:

$$\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} P_{mnt}\, q_{mnt} \qquad \forall \quad m, n, t$$

4.2.2 Holding Cost

Costs are associated with holding the inventory at the distributor and manufacturers at different echelons in the network. In general, the cost incurred over a given time period t under a particular scenario is proportional to the average amount of inventory held over this period. This inventory is expressed by the arithmetic mean of the starting and finishing inventories for the period, as inventories vary linearly over each time period. The term associated with the holding cost by distributor is given by:

$$\sum_{d=1}^{D}\sum_{n=1}^{N}\sum_{t=1}^{T} H_{dnt}\left(\sum_{m=1}^{M}\sum_{t=1}^{T} X_{mdnt} - \sum_{r=1}^{R}\sum_{t=1}^{T} Y_{drnt}\right) \qquad \forall \quad m, n, t$$

Cost of defective goods storage by manufacturer is as follow:

$$\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} h_{mnt}\ d_{mnt} \qquad \forall\ m, n, t$$

Summing up the terms form the total holding cost for the objective function that will minimize the total,

$$\sum_{d=1}^{D}\sum_{n=1}^{N}\sum_{t=1}^{T} H_{dnt}\left(\sum_{m=1}^{M}\sum_{t=1}^{T} X_{mdnt} - \sum_{r=1}^{R}\sum_{t=1}^{T} Y_{drnt}\right) + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} h_{mnt}\, d_{mnt} \qquad \forall\ m, n, t$$

4.2.3 Transportation Cost

The total transportation cost under a particular scenario is proportional to the amount of material transferred between echelons. Transportation costs between production plant to warehouse and distribution centers to customers are included. Transportation cost for products from manufacturer to distributor to retailer is given by,

$$\sum_{m=1}^{M}\sum_{d=1}^{D}\sum_{n=1}^{N}\sum_{t=1}^{T} G_{mdnt}\ X_{mdnt} \qquad \forall\ m, n, t$$

$$\sum_{d=1}^{D}\sum_{r=1}^{R}\sum_{n=1}^{N}\sum_{t=1}^{T} g_{drnt}\ Y_{drnt} \qquad \forall\ m, n, t$$

Another cost incurs due to transport the defective products from manufacturer to storage and vice versa by manufacturer,

$$\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} z_{mnt}\, d_{mnt} \qquad \forall\ m, n, t$$

Summing up the terms form the total transportation cost for the objective function:

$$\sum_{m=1}^{M}\sum_{d=1}^{D}\sum_{n=1}^{N}\sum_{t=1}^{T} G_{mdnt}\, X_{mdnt} + \sum_{d=1}^{D}\sum_{r=1}^{R}\sum_{n=1}^{N}\sum_{t=1}^{T} g_{drnt}\, Y_{drnt} + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} z_{mnt} d_{mnt} \qquad \forall\ m, n, t$$

4.2.4 Rework Cost

Sometimes reworking of defective goods can be quite profitable if the cost of production is high, raw materials are limited or finished goods are costly. Here, it is assumed that all defective goods take same amount of time and cost to rework by the manufacturers.

$$\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} R_{mnt}\, d_{mnt} \qquad \forall\ m, n, t$$

4.2.5 Discount Cost

Reworking of defective goods is not always quite profitable if the cost of production is comparatively low and raw materials are available. In such cases defective goods as these items may be sold at discount by manufacturers,

$$\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} D_{mnt}\, Sr_{mnt} \qquad \forall\ m, n, t$$

4.2.6 Shortage Cost

Shortage of the finished part causes the finished assembled product to be held up unreleased. Shortage cost of products in manufacturer varies with the amount of defectives produced by manufacturer.

$$\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} Sh_{mnt}\, d_{mnt} \qquad \forall\ m, n, t$$

4.2.7 Cost of Service

The cost of providing a service associated with having employees, IT, bookkeeping, maintenances etc. to perform valuable tasks to a certain level.

$$\sum_{t=1}^{T} Sc_{mnt}\, Tt \qquad \forall\ m, n, t$$

Hence, the objective function is:

$$\begin{aligned} Z_{min} = {} & \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} P_{mnt}\, q_{mnt} + \sum_{d=1}^{D}\sum_{n=1}^{N}\sum_{t=1}^{T} H_{dnt}\left(\sum_{m=1}^{M}\sum_{t=1}^{T} X_{mdnt} - \sum_{r=1}^{R}\sum_{t=1}^{T} Y_{drnt}\right) \\ & + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} h_{mnt}\, d_{mnt} + \sum_{m=1}^{M}\sum_{d=1}^{D}\sum_{n=1}^{N}\sum_{t=1}^{T} G_{mdnt}\, X_{mdnt} \\ & + \sum_{d=1}^{D}\sum_{r=1}^{R}\sum_{n=1}^{N}\sum_{t=1}^{T} g_{drnt}\, Y_{drnt} + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} z_{mnt}\, d_{mnt} \\ & + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} R_{mnt}\, d_{mnt} + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} D_{mnt}\, Sr_{mnt} \\ & + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} Sh_{mnt}\, d_{mnt} + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} Sc_{mnt}\, Tt \qquad \ldots\ldots\ldots\ldots(1) \end{aligned}$$

Constraints: The objective function is subjected to the following constraints:

1. Production capacity of each plant is limited for a specific product in a certain time period. The production rate of each product at any plant cannot exceed this certain limit that restricts the production capacity of the manufacturers.

$$q_{mnt} \leq C_{mnt} \qquad \forall\ m, n, t \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

2. The amount of defective goods can be calculated by the percentage of the defectives of the total production quantity of certain product by the manufacturers.

$$d_{mnt} = p_{mnt} . q_{mnt} \quad \forall \;\; m, n, t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

3. Again the amount of scrap goods can be calculated by the percentage of the scrap products of the produced defective quantity of certain product by the manufacturers after reworking.

$$Sr_{mnt} = s_{mnt} . d_{mnt} \quad \forall \;\; m, n, t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

4. Amount of perfect product before reworking can be counted in terms of the percentage of defective goods produced by manufacturer in each time period.

$$n_{mnt} = (1- p_{mnt}) . q_{mnt} \quad \forall \;\; m, n, t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

5. The total amount of perfect goods by manufacturers in a particular time period after rework is the sum of the perfect product produced and the amount of the perfect product after reworking.

$$N_{mnt} = n_{mnt} + d_{mnt} - Sr_{mnt} \quad \forall \;\; m, n, t \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

6. There are delivery capacity limitations due to the storage capacity of the distributors for all types of products.

$$\sum_{m=1}^{M} \sum_{n=1}^{N} X_{mdnt} \leq A_{dt} \quad \forall \;\; d, t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

7. There are delivery capacity limitations due to the storage capacity of the distributors for each type of product.

$$\sum_{m=1}^{M} X_{mdnt} \leq A_{dnt} \quad \forall \;\; d, n, t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

8. There are delivery capacity limitations due to the storage capacity of the retailers for all types of products.

$$\sum_{d=1}^{D} \sum_{n=1}^{N} Y_{drnt} \leq B_{rt} \quad \forall \;\; r, t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

9. There are delivery capacity limitations due to the storage capacity of the retailers for each type of product.

$$\sum_{d=1}^{D} Y_{drnt} \leq B_{rnt} \quad \forall \;\; r, n, t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

10. The total demands of the retailers have to be covered by the amount of perfect goods by the manufacturers after reworks.

$$\sum_{r=1}^{R} R_{rnt} \leq \sum_{m=1}^{M} N_{mnt} \qquad \forall \quad n, t \qquad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

11. The sum of the scrap goods and the demands of the retailer is the total production of the manufacturers in a particular time period.

$$\sum_{r=1}^{R} R_{rnt} + \sum_{m=1}^{M} Sr_{mnt} \leq \sum_{m=1}^{M} q_{mnt} \qquad \forall \quad n, t \qquad \ldots\ldots (12)$$

12. The defectives make the shortage of the finished part that causes the finished assembled product to be held up unreleased. The amounts of shortage at the manufactures due to defective goods can be counted by the total demand and the total perfect goods produced by the manufactures.

$$\sum_{m=1}^{M} d_{mnt} = \sum_{r=1}^{R} R_{rnt} - \sum_{m=1}^{M} n_{mnt} \qquad \forall \quad n, t \qquad \ldots\ldots\ldots(13)$$

13. Amount of perfect product by manufacturers before rework is less or equal to the demand for retailer of the products that can investigate the amount of shortage due to defectives.

$$\sum_{m=1}^{M} n_{mnt} \leq \sum_{r=1}^{R} R_{rnt} \qquad \forall \quad n, t \qquad \ldots\ldots\ldots\ldots(14)$$

14. After removing the scraps the total products transported from the manufacturers to the distributors are perfect in quality.

$$\sum_{d=1}^{D} X_{mdnt} \leq N_{mnt} \qquad \forall \quad m, n, t \qquad \ldots\ldots\ldots\ldots\ldots\ldots(15)$$

15. There is no inventory at the distributors in the beginning and at the end of the specific time period.

$$\sum_{r=1}^{R}\sum_{t=1}^{T} Y_{drnt} \leq \sum_{m=1}^{M}\sum_{t=1}^{T} X_{mdnt} \qquad \forall \quad d, n, t \neq T \qquad \ldots\ldots (16)$$

16. The total demands of the retailers during the specific time period will be filled up.

$$\sum_{d=1}^{D} Y_{drnt} = \sum_{r=1}^{R} R_{rnt} \qquad \forall \quad d, n, t \qquad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

17. The available time for the production facilities of all production processes by the manufacturers is limited.

$$\sum_{m=1}^{M}\sum_{n=1}^{N} a_{mnt}\, q_{mnt} \leq Ta \qquad \forall \quad t, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(18)$$

18. The available time for the production facilities of all rework processes by the manufacturers is limited.

$$\sum_{m=1}^{M} \sum_{n=1}^{N} b_{mnt}\, d_{mnt} \leq Tb \qquad \forall \quad t, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(19)$$

19. The total length of each period is limited to the sum of total production time and total rework time by the manufacturers.

$$Ta + Tb \leq Tt \qquad \forall \quad t \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

20. Eq. (21)indicates that the production amount, deliveries to warehouses and retailers, retailer shortages, scrap goods, defective goods, and perfect goods before and after reworking should all have positive values.

$$X_{mdnt},\ Y_{drnt},\ q_{mnt},\ Sh_{mnt},\ d_{mnt},\ Sr_{mnt},\ n_{mnt},\ N_{mnt} \geq 0 \qquad \forall \quad m, d, r, n, t, \quad \ldots\ldots (21)$$

CHAPTER 5

SOLUTION APPROACH BY GENETIC ALGORITHM

5.1 Solution approach

This chapter represents the solution techniques that can be applied to solve the constructed model. Recently, there are several optimization programs available in the market. Each of them provides different advantages and disadvantages. Genetic Algorithm has been chosen to apply in this model because of its usability and availability, extensive answer space, lower number of infeasible answers, high probability of reaching the global optimum. It can work with many decision variables and can search the problem space from multiple directions. However, most other algorithms are not able to run in parallel and can only search the problem space from one direction at a time.

The GA is quick to implement and the concept is very easy to understand in practice. Moreover, here GA is reasonable to use as this study aims to optimize a single problem on a single time. Again, several set of solutions is compared with that of LINPROG in order to demonstrate and validate the optimization model equations and their behavior.

5.2 Genetic Algorithm

The Genetic Algorithm (GA) module in Matlab‟s global optimization toolbox is used to solve model. Genetic algorithms are inspired by Darwin's theory about evolution. It is a stochastic search method for solving both constrained and unconstrained optimization problems that is based on a natural selection process (*www.mathworks.com*). It explores the solution space by using concepts taken from natural genetics [72] and evolution theory [73].

GA starts with an initial population. The individuals of the population are called chromosomes which are selected according to a predefined fitness function, in this case the total cost. The chromosomes evolve through successive iterations called generations. It is created by changing chromosomes in the existing population through crossover and mutation. This is repeated until some condition is satisfied. This motivates that the new population will be better than the previous one. Each chromosome includes several genes which represents an order quantity of item n at time point t. For example [74], if we have 10 items and 12 time points, we will have 120 genes (order quantities) in one chromosome, Figure 5.1.

Q_1^1	Q_1^2	Q_1^3	…	Q_1^{12}	Q_2^2	…	Q_2^{12}	…	Q_{10}^{12}

Figure: 5.1 Chromosomes with 120 genes

The fitness function determines the ability of an individual to compete with other individuals. It gives a fitness score to each individual. Based on its fitness score an individual will be selected for reproduction. To solve instances of the model the syntax is given in which the initial population, generation, crossover and mutation are random. The process first deals with the input parameters. The fitness function, the total cost, is *fitnessfnc***.** The number of integer variables is *nvars.*

[x,fval] = ga(@fitnessfun, nvars)

A is a matrix for linear inequality constraints and *b* is a vector for linear inequality constraints. The symbol "[]" represents a placeholder for a matrix of the constraints.*LB* and *UB* are the vectors of lower and upper bounds, respectively. And the last input is *Options*. The output parameters of GA are *x* which is the best point that GA located during its generations and *fval* is a fitness function evaluated at *x*. The algorithm stops as soon as any one of the conditions is met. GA uses the penalty fitness value instead of the fitness value for stopping criteria. The last output parameter is *output* that gives information about algorithm performance.

5.2.1 Chromosomes

Chromosomes are like strings of DNA and serves as a model for the whole organism of a living cell. A chromosome consists of genes, blocks of DNA. Each gene has its own position called locus in the chromosome. Complete set of genetic material (all chromosomes) is called genome.

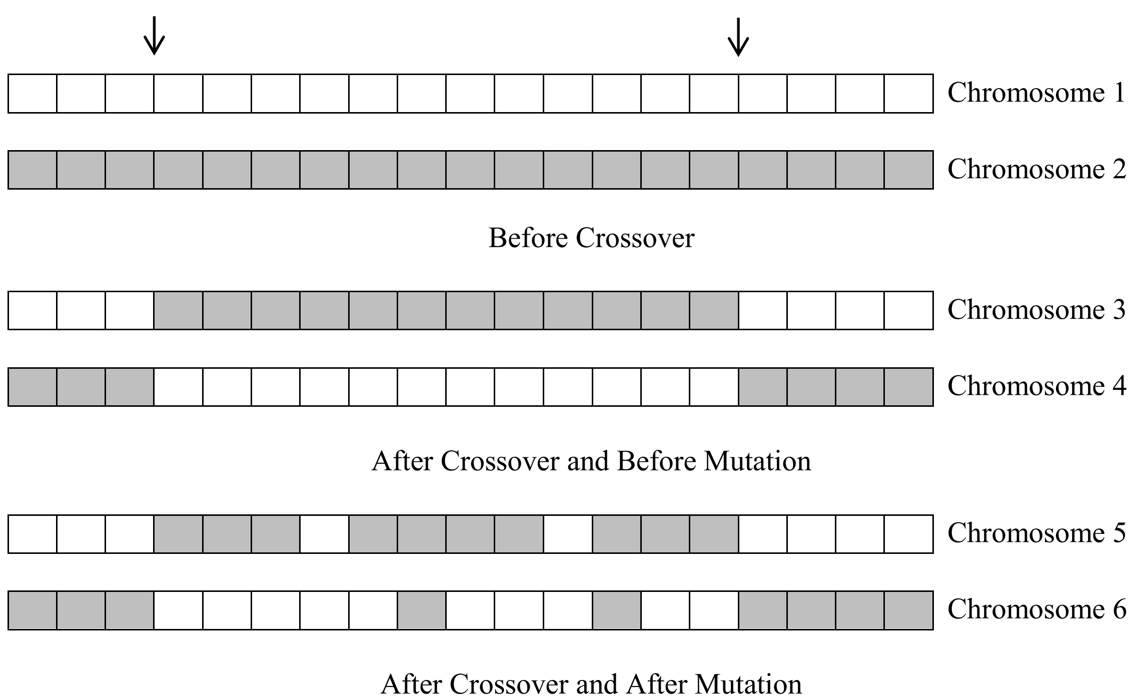

Figure: 5.2 Crossovers and Mutation

Particular set of genes in genome is called genotype. The selection of chromosomes is one of the important components of the GA. Good results and amount of run time depends on the selection of the best chromosomes.

5.2.2 Initial Population

The algorithm starts with a set of individuals that is called a Population. The individuals are ranked based on their fitness and the chromosomes are arranged based on the value of the objective function. Each individual is a solution to the problem. Each individual is characterized by a set of parameters (variables). To form a Chromosome (solution) genes are joined into a string. The set of genes of an individual is represented using binary values (string of 1s and 0s)*(www.mathworks.com)*.

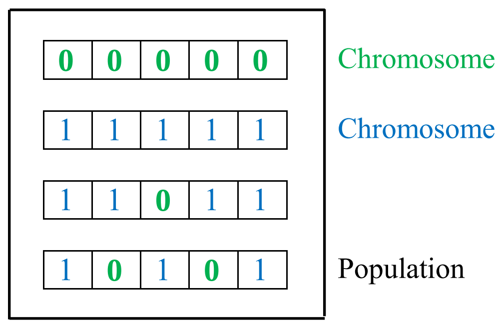

Figure: 5.3 Chromosomes and Population

The GA begins by generating a random initial population, as shown in the following figure. For example *(www.mathworks.com)*, the initial population contains 20 individuals that are lying in the upper-right quadrant of the Figure: 5.4.

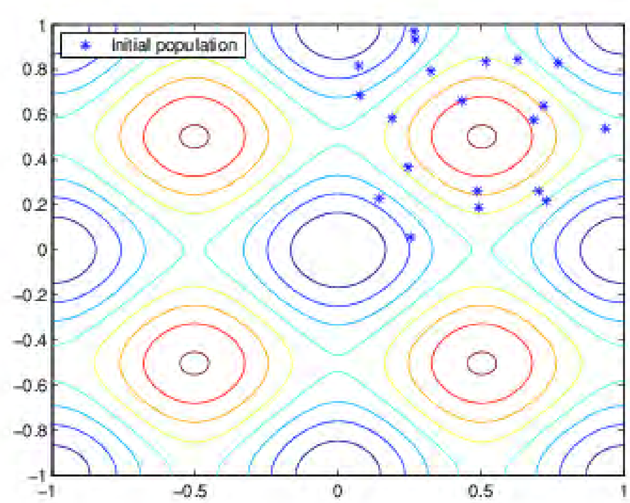

Figure: 5.4 Initial Populations

That means their coordinates lie between 0 and 1. Here, the Initial range in the Population options is [0 1]. It can be settled the Initial range by knowing the approximate minimal point for a function.

Population size is an important parameter of GA. It says how many chromosomes are in one generation. If there are too few chromosomes, GA has a few possibilities to perform crossover and only a small part of search space is explored. On the other hand, with a large population size, the GA searches the solution space more thoroughly to increase the chance of getting a global minimum rather than a local minimum. But, if there are too many chromosomes, GA slows down. Research shows that after some limit (which depends mainly on encoding and the problem) it is not useful to increase population size, because it does not make solving the problem faster. *(www.obitko.com)*

5.3. GA Operations

The following recounts the fundamental operations of the Genetic Algorithm. Different types of children like Elite, Crossover and Mutation are generated in each generation. This section explains how the algorithm performs the crossover, mutation, selection and termination.

5.3.1. Crossover Children

The GA generates crossover children by combining pairs of parents in the current population. Crossover selects genes from parent chromosomes and creates a new offspring. Thenthe new offspring are added to the population. At each coordinate of the child vector, the default crossover function is selected randomly. The easiest way how to do this is to choose randomly some crossover point and everything before this point copy from a first parent and then everything after a crossover point copy from the second parent.

Crossover Point

Chromosome 1	11011 | 00100110110
Chromosome 2	11011 | 11000011110
New Offspring 1	11011 | 11000011110
New Offspring 2	11011 | 00100110110

For problems with linear constraints, the default crossover function creates the child as a random weighted average of the parents. For example *(www.obitko.com)*, consider the crossover point to be 5 as shown below (| is the crossover point). Crossover is the most significant phase in a genetic algorithm. Specific crossover made for a specific problem can improve performance of the genetic algorithm.

5.3.2. Mutation Children

After a crossover is performed, mutation takes place. In this study, the GA generates mutation children by randomly changing the genes of individual parents. This is to prevent falling all solutions in population into a local optimum of solved problem. For bounded or linearly constrained problems, the child remains feasible. Mutation changes randomly the new offspring. This implies that some of the bits in the bit string can be flipped. For binary encoding it can switch a few randomly chosen bits from 1 to 0 or from 0 to 1. Mutation can then be following:

Native 1	1101111000011110
Native 2	1101100100110110
Mutated 1	1100111000011110
Mutated 2	1101101100110110

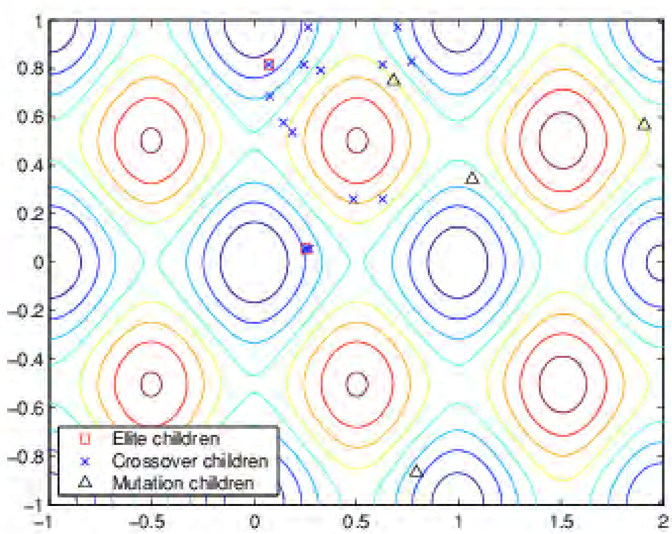

Figure: 5.5 Elite, Crossover and Mutation Children

Here, the mutation probability refers to the probability of change in any gene of a chromosome. Each chromosome receives a certain number of genes that are assumed to change. The number is obtained by multiplying the total number of genes by this probability. For instance, if the mutation probability is 0.2 and m = 2, n = 1 and t = 2, the total number of genes required to undergo mutation is as follows:

$$0.2\times2\times1\times2 = 0.8 \approx 1 \text{ (nearest whole number)}$$

Mutation occurs to retain diversity within the population and prevent premature convergence. The mutation depends on the encoding and crossover. For example *(www.mathworks.com)*, mutation could be exchanging two genes when there are encoding permutations. The following figure shows the children of the population at the second generation, and indicates whether they are elite, crossover or mutation children.

5.3.3 Selection Phase

Selection phase is to select the fittest individuals and let them pass their genes to the next generation. Based on their fitness scores two pairs of parents are selected. Parents with high fitness are more likely to be selected for reproduction.

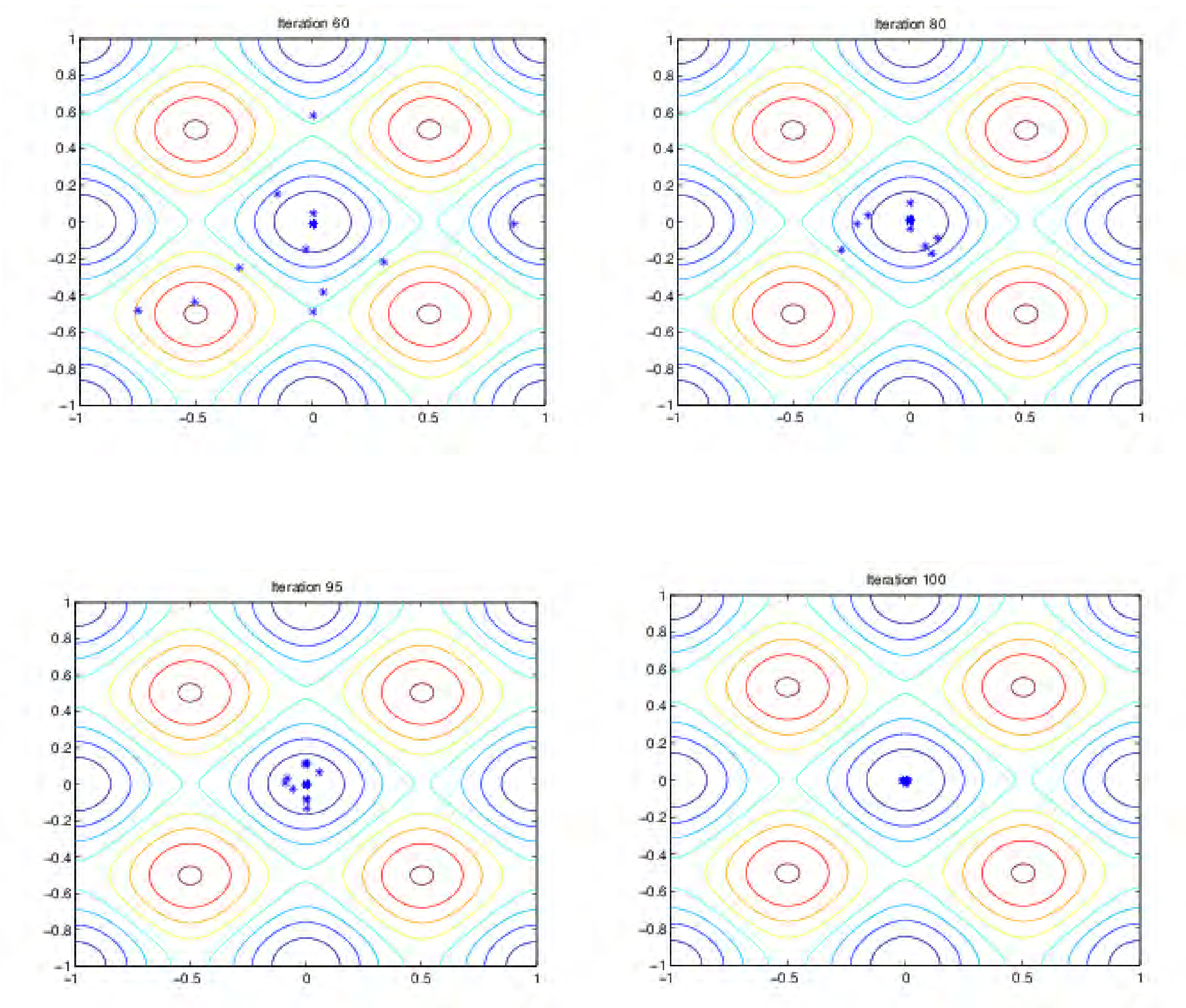

Figure: 5.6 Populations at different iterations

In this phase, firstly, the selection function chooses parents deterministically for the next generation based on the integer part of their scaled values (expectation values). An individual can be selected more than once as a parent. For instance, if a parent's scaled value is 3.2, the function selects that individual twice as a parent.

In the next step, using the fractional parts of the scaled values, the selection function selects additional parents. The next generation‟s chromosomes are selected from these chromosomes according to the population size. Finally, the best chromosomes were selected for the next generation. Figure: 4.6 show the populations at different iterations.

5.3.4 Termination Criteria

The GA stops according to different criteria in the Stopping criteria pane in the Optimization application like Generations, Time limit, Fitness limit, Function tolerance etc. GA terminates as soon as any one of these conditions is met. It implies that the population does not produce offspring which are significantly different from the antecedent generation. Then it is said that the genetic algorithm has provided a set of solutions to the problem.

So, the process of selection starts with the selection of fittest individuals from a fixed population. They produce new offspring with inherit characteristics of the parents. As new generations are formed, individuals with least fitness die to provide space for the new offspring. The sequence of phases is repeated to produce individuals in each new generation which are better than the previous one. At the end, the generation with the fittest individuals is founded.

CHAPTER 6

RESULT AND DISCUSSION

6.1 Introduction

In this chapter, results of the defective goods supply chain cost optimization model applied to two real world supply chain are presented. As there are not too many empirical studies on defective goods supply chain, providing results on the impact of different types of costs by means of empirical data could be of great value. Therefore, two real-world supply chains are described to further illustrate the different aspects of supply chain costs. To be precise, this analysis wants to test and quantify the practicability and performance of the model by means of two renowned real manufacturing company"s supply chains in Bangladesh. Supply chain-1(SC-1) manufactures steel products considering rework of defective goods and supply chain-2(SC-2) manufactures apparel products not considering rework of defective goods. In addition, recommendations of the model based on the results analysis of real cases are explained.

6.2 Model Testing

The mathematical model developed in Chapter 4 is tested for two reasons, firstly to prove its functionality, and secondly to analyze the conflicting objectives. Therefore, two real cases problems for two SCs are designed and the model is solved with a specific solving technique, as illustrated in Chapter 5. Then the end results from the test is analyzed and presented in a suitable way. For that reason, this part is divided in three sections:

1. Design the Case and Data Population
2. Solving Method Characteristics
3. Presentation of results and Sensitivity Analysis

First of all the real case SCs are constructed and populated with all the necessary data that is suitable for testing the problem, in order to have proper outcomes for assessing the model. Furthermore, the solving method characteristics and settings are determined, for having an efficient approach towards the solving process. At the end, the actual tests are performed, and the solutions are analyzed in a proper way for having quality conclusions. It should be mentioned that due to confidentiality, the pseudo name of the companies and some masked data are used in this illustration.

6.2.1 Design of the Case and Data Population

In particular, it is chosen a three echelon supply chain compiled out of two plants for converting raw materials to final product. Warehouse options among which any one can be chosen to satisfy the objective, distribution centers (DC) and customer zones are also considered to design the case. The supply chain problem is assuming production of one kind product, where two potential plants can be chosen for its production.

In order to enable the solving of the model to generate concrete results, it is populated with data. For that reason a collection of data is performed, where data are picked from various sources, some reasonable assumptions are taken, and all the necessary calculations are done. The data are collected with help from the Enterprise Resource Planning (ERP)-system and interviews which is mainly focused on the costs (BDT) and time (hours) of the different facilities of the supply chain.

In designing the case problems, several aspects are taken into considerations. It begins from the availability of data, and the possibility of having real business supply chains. The transformation of the data for populating the models is sometimes a highly complex task. The reason for these simplifications is partially explained above, but it lays in the complexity of the mathematical model that can be a highly delicate procedure, where not just using genetic algorithms should be a standard way. Even though, this is considered as efficient and reasonable enough to be done within a frame of this thesis research, the testing case can be upgraded in the future, where a more complex supply chain problem will be addressed as discussed in Chapter 7.

6.2.2 Characteristics of Solving Method

For the solving process, as mentioned before in Chapter 4, Genetic Algorithm in Matlab is used. The program is implemented in Matlab R2013b, on a PC platform with an Intel core i3 processor and 2GB RAM. This program is combining the Matlab scripts and Graphic User Interphase (GUI) script that is plotting the results from the generations run. There are some necessary adjustments that are not in the scripts themselves, but in the way of writing the functions in Matlab language. It is necessary to transform the mathematical formulation of the model into a specific programming language. Moreover, during the understanding the behavior of the algorithm and testing the mathematical model in this version, several small problems are run in order to define the best settings. Afterwards, the following parameters are set:

- The initial population is defined by using uniform distributed random numbers between the lower and upper bounds. (This is done, since there is no existing previous optimization data)
- Initial population size: 100
- Maximum number of generations: 100
- Number of variables: 17
- Number of constraints: 33

Table 6.1: Production cost of unit producing product n by manufacturer m during time period t under the SC-1 & SC-2 (P_{mnt}), BDT/Pcs

Time period t=1, Supply Chain =1				Time period t=1, Supply Chain =2		
Product (n)	**Plant (m)**			**Product (n)**	**Plant (m)**	
	1	**2**			**1**	**2**
Anchor rod	305	308		T-shirt	130	135

Table 6.2: Material holding cost of each product n by distributor d during time period t under the SC-1 & SC-2(H_{dnt}), BDT/Pcs

Time period t=1, Supply Chain =1			Time period t=1, Supply Chain =2	
Product (n)	**Warehouse (d)**		**Product (n)**	**Warehouse (d)**
	1			**1**
Anchor rod	0.30		T-shirt	0.40

Table 6.3: Material holding cost of each defective product n by manufacturer m during time period t under the SC-1 & SC-2 (h_{mnt}), BDT/Pcs

Time period t=1, Supply Chain =1				Time period t=1, Supply Chain =2		
Product (n)	**Plant (m)**			**Product (n)**	**Plant (m)**	
	1	**2**			**1**	**2**
Anchor rod	0.10	0.13		T-shirt	0.10	0.12

Table 6.4: Unit transportation cost of product n transferred from manufacturer m to distributor d during time period t under the SC-1 & SC-2 (G_{mdnt}), BDT/Pcs

Time period t=1, Supply Chain =1			Time period t=1, Supply Chain =2	
Plant (m)	**Warehouse (d)**		**Plant (m)**	**Warehouse (d)**
	1			**1**
1	0.15		**1**	0.15
2	0.16		**2**	0.17

Table 6.5: Unit transportation cost of product n transferred from distributor d to retailer r during time period t under the SC-1 & SC-2 (g_{drnt}), BDT/Pcs

Time period t=1, Supply Chain =1			Time period t=1, Supply Chain =2	
Warehouse (d)	**Warehouse (r)**		**Warehouse(d)**	**Warehouse (r)**
	1			**1**
1	0.50		**1**	0.70

Table 6.6: Unit transportation cost of defective product n transferred from manufacturer m to storage s during time period t under the SC-1 & SC-2 (z_{mnt}), BDT/Pcs

Time period t=1, Supply Chain =1			Time period t=1, Supply Chain =2	
Plant (m)	**Storage (s)**		**Plant (m)**	**Storage (s)**
	1			**1**
1	0.04		**1**	0.04
2	0.05		**2**	0.05

Table 6.7: Rework cost of unit defective product n by manufacturer m during time period t under the SC-1 & SC-2 (R_{mnt}), BDT/Pcs

Time period t=1, Supply Chain =1				Time period t=1, Supply Chain =2		
Product (n)	**Plant (m)**			**Product (n)**	**Plant (m)**	
	1	**2**			**1**	**2**
Anchor rod	5	7		T-shirt	0	0

Table 6.8: Discount cost of unit scrap product n for sale by manufacturer m during time period t under the SC-1 & SC-2 (D_{mnt}), BDT/Pcs

Time period t=1, Supply Chain =1				Time period t=1, Supply Chain =2		
Product (n)	**Plant (m)**			**Product (n)**	**Plant (m)**	
	1	**2**			**1**	**2**
Anchor rod	0	0		T-shirt	15	16

Table 6.9: Shortage cost of unit product n in manufacturer m during time period t under the SC-1 & SC-2 (Sh_{mnt}), BDT/Pcs

Time period t=1, Supply Chain =1				**Time period t=1, Supply Chain =2**		
Product (n)	**Plant (m)**			**Product (n)**	**Plant (m)**	
	1	**2**			**1**	**2**
Anchor rod	0.35	0.37		T-shirt	0.10	0.10

Table 6.10: Service cost of unit product or service n in manufacturer m during time period t under the SC-1 & SC-2 (Sc_{mnt}), BDT/Pcs

Time period t=1, Supply Chain =1				**Time period t=1, Supply Chain =2**		
Product (n)	**Plant (m)**			**Product (n)**	**Plant (m)**	
	1	**2**			**1**	**2**
Anchor rod	0	0		T-shirt	0	0

Table 6.11: Maximum production capacity for manufacturer m for product n at time period t under the SC-1(C_{mnt}), Pcs/month (26 days) & SC-2 (C_{mnt}), Pcs/week (6 days) (it is assumed that production capacity do not change with time, so it remains same for all the time periods and scenarios).

Time period t=1, Supply Chain =1				**Time period t=1, Supply Chain =2**		
Product (n)	**Plant (m)**			**Product (n)**	**Plant (m)**	
	1	**2**			**1**	**2**
Anchor rod	41000	35000		T-shirt	25000	30000

Table6.12: Maximum material holding capacity for distributor d at time period t under the SC-1 (A_{dt}), Pcs/month & SC-2 (A_{dt}), Pcs/week.

Time period t=1, Supply Chain =1			**Time period t=1, Supply Chain =2**	
Product (n)	**Warehouse (d)**		**Product (n)**	**Warehouse (d)**
	1			**1**
Anchor rod	150000		T-shirt	120000

Table6.13: Maximum material holding capacity for distributor d for product n at time period t under the SC-1 (A_{dnt}), Pcs/month & SC-2 (A_{dnt}), Pcs/week.

Time period t=1, Supply Chain =1			Time period t=1, Supply Chain =2	
Product (n)	**Warehouse (d)**		**Product (n)**	**Warehouse (d)**
	1			**1**
Anchor rod	60000		T-shirt	50000

Table6.14: Maximum material holding capacity for retailer r at time period t under the SC-1 (B_{rt}), Pcs/month & SC-2 (B_{rt}), Pcs/week.

Time period t=1, Supply Chain =1			Time period t=1, Supply Chain =2	
Product (n)	**Warehouse (r)**		**Product (n)**	**Warehouse (r)**
	1			**1**
Anchor rod	30000		T-shirt	30000

Table6.15: Maximum material holding capacity for retailer r for product n at time period t under the SC-1 (B_{rnt}), Pcs/month & SC-2 (B_{rnt}), Pcs/week.

Time period t=1, Supply Chain =1			Time period t=1, Supply Chain =2	
Product (n)	**Warehouse (r)**		**Product (n)**	**Warehouse (r)**
	1			**1**
Anchor rod	10000		T-shirt	10000

Table6.16: Percentage of defective goods n produced by manufacturer m at time period t under the SC-1 & SC-2 (p_{mnt}), Pcs (it is assumed that the % does not change with time, so it remains same for all the time periods and scenarios).

Time period t=1, Supply Chain =1				Time period t=1, Supply Chain =2		
Product (n)	**Plant (m)**			**Product (n)**	**Plant (m)**	
	1	**2**			**1**	**2**
Anchor rod	30%	35%		T-shirt	4%	5%

Table 6.17: Percentage of perfect goods n produced by manufacturer m at time period t under the SC-1 & SC-2 (1- p_{mnt}), Pcs (it is assumed that the % does not change with time, so it remains same for all the time periods and scenarios).

Time period t=1, Supply Chain =1				**Time period t=1, Supply Chain =2**		
Product (n)	**Plant (m)**			**Product (n)**	**Plant (m)**	
	1	**2**			**1**	**2**
Anchor rod	70%	65%		T-shirt	96%	95%

Table6.18: Percentage of scrap goods n produced by manufacturer m at time period t under the SC-1 & SC-2 (Sr_{mnt}), Pcs (it is assumed that the % does not change with time, so it remains same for all the time periods and scenarios).

Time period t=1, Supply Chain =1				**Time period t=1, Supply Chain =2**		
Product (n)	**Plant (m)**			**Product (n)**	**Plant (m)**	
	1	**2**			**1**	**2**
Anchor rod	0%	0%		T-shirt	4%	5%

Table 6.19: Time (hr) required to produce unit product n by manufacturer m at time period t under the SC-1 & SC-2 (a_{mnt}), hr./pcs (it is assumed that the % does not change with time, so it remains same for all the time periods and scenarios).

Time period t=1, Supply Chain =1				**Time period t=1, Supply Chain =2**		
Product (n)	**Plant (m)**			**Product (n)**	**Plant (m)**	
	1	**2**			**1**	**2**
Anchor rod	0.02	0.03		T-shirt	0.02	0.02

Table 6.20: Time (hr) required to rework unit product n by manufacturer m at time period t under the SC-1 & SC-2 (b_{mnt}), Hr/pcs (it is assumed that the % does not change with time, so it remains same for all the time periods and scenarios).

Time period t=1, Supply Chain =1				**Time period t=1, Supply Chain =2**		
Product (n)	**Plant (m)**			**Product (n)**	**Plant (m)**	
	1	**2**			**1**	**2**
Anchor rod	0.04	0.05		T-shirt	0	0

6.3 Results Analysis

Results are analyzed at several levels to answer the research questions for the supply chains. At the first stage, an optimization run is performed to achieve the numerical values of a set of variables which satisfy all the constraints and provides the optimal value of the objective function. At the second stage, ranges of the objective functions was analyzed as it provides vital information to the decision maker about the desired level of the objectives. At the third stage, in sensitivity analysis, several set of solutions is compared with that of LINPROG to demonstrate the performance of the model.

6.3.1 Supply chain 1: Anchor rod manufacturing (XSL)

The company considered here for SC-1 has low labor cost and efficient production machinery that offers the strength and competitive advantage with low production cost. But due to the high raw materials cost, it considers the rework of the defective items. The factories endure the high logistics cost and time due to rework the defective items that pushes the management difficult to make decisions regarding the efficiency.

An overview of X Steel Ltd.: X Steel Ltd. (XSL) is a well-established and the most modern steel fabrication company in Bangladesh. Equipped with state of the art machines XSL is able to manufacture high quality galvanized Telecom and Transmission towers & telescopic steel poles, hardware fittings, portable steel bridges and screws. In the power transmission sector, XSL is the first manufacturer and supplier of Transmission towers in Bangladesh, which in turn allowed the country for the first time not to import towers from abroad and therefore utilize the nation"s wealth for other infrastructural development work. In the telecom sector, the company is also the biggest country-leading manufacturer and supplier of telecom towers and steel poles. Having supplied telecom towers & steel poles to foreign buyers in Kuwait, Malaysia, Maldives, Nepal and Bhutan the company is poised to expand its international market even further.

6.3.1.1 Analysis of total Supply Chain cost function

Table 6.21 depicts that the total supply chain cost. The decision maker can choose any value from this range of costs trading off the corresponding values of the other variables and constraints. The developed model is solved seven times by the GA to demonstrate the performance accuracy using the same parameter from the tables in Section 6.2. The results are slightly divergent because of choosing the statistical distributions for the values of the parameters. The values of Z_{min} of each run from the GA are illustrated in Table 6.21. Additionally, the best output of the solution (out of seven runs) is presented in Table 6.22.

Table 6.21: Values of objective functions Z_{min}

Run	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7
$\mathbf{Z_{min}}$	6155365.38	6155365.38	6155365.39	6155365.39	**6155365.38**	6155365.38	6155365.38

6.3.1.2 Analysis of decision variables for a set of solution

At this stage of analysis a set of solution has been elaborated with the values of 17 decision variables. This solution set has been taken from the GA generated in run 5. The optimum costs, amounts of Economic Production Quantity, defective goods, perfect goods of the Supply chain-1 for run 5 are shown in Table 6.22.

Table 6.22: Values of decision variables for a set of solution (run 5)

Variable	**Run 1**	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**	**Run 7**
$\mathbf{X_1}$	10752.689	10752.689	10752.688	10752.689	10752.689	10752.689	10752.688
$\mathbf{X_2}$	9247.310	9247.310	9247.311	9247.310	9247.310	9247.310	9247.311
$\mathbf{X_3}$	9247.309	9247.309	9247.311	9247.310	9247.309	9247.310	9247.311
$\mathbf{X_4}$	9247.310	9247.310	9247.312	9247.311	9247.310	9247.310	9247.312
$\mathbf{X_5}$	9247.310	9247.309	9247.311	9247.310	9247.310	9247.309	9247.311
$\mathbf{X_6}$	1505.376	1505.376	1505.375	1505.376	1505.375	1505.376	1505.375
$\mathbf{X_7}$	1572.043	1572.043	1572.043	1572.043	1572.043	1572.043	1572.043
$\mathbf{X_8}$	0.003	0.769	2.810	0.224	0.003	0.003	0.121
$\mathbf{X_9}$	0.731	0.702	0.074	0.159	0.035	0.008	0.018
$\mathbf{X_{10}}$	9247.312	9247.312	9247.312	9247.312	9247.311	9247.312	9247.312
$\mathbf{X_{11}}$	7675.268	7675.268	7675.268	7675.268	7675.268	7675.268	7675.269
$\mathbf{X_{12}}$	10752.688	10752.689	10752.687	10752.689	10752.687	10752.688	10752.688
$\mathbf{X_{13}}$	9247.310	9247.312	9247.311	9247.310	9247.311	9247.311	9247.311
$\mathbf{X_{14}}$	9247.311	9247.311	9247.311	9247.311	9247.311	9247.311	9247.311
$\mathbf{X_{15}}$	277.426	277.423	277.421	277.419	277.435	278.392	277.420
$\mathbf{X_{16}}$	78.801	78.606	78.616	78.604	78.714	78.606	78.604
$\mathbf{X_{17}}$	357.012	356.068	356.041	356.025	356.331	357.115	356.057

Here, $X_1=q_{111}$, $X_2=q_{211}$, $X_3= X_{111}$, $X_4= Y_{1111}$, $X_5= X_{2111}$, $X_6= d_{111}$, $X_7= d_{211}$, $X_8= Sh_{111}$, $X_9= Sh_{211}$, $X_{10}= n_{111}$, $X_{11}= n_{211}$, $X_{12}= N_{111}$, $X_{13}= N_{211}$, $X_{14}= r_{111}$, $X_{15}= Ta_t$, $X_{16}= Tb_t$, $X_{17}= Tt_t$. As the total length of each period is limited to the sum of total production time and total rework time by the manufacturers, any change in the production and rework time has a direct effect on the production rate. The model searches for the best path using the parameters to get the optimum values of the variables that are shown in Table 6.22 for the run 5. In addition, the required production time to fulfill the retailer demands is also presented. The model suggests that with the increments in the production and rework times, the total costs decreased. Figure 6.1 shows the curves for Z_{min} (best) and Z_{min} (average) for run 5. It plots the best function value in each generation with respect to iteration number. The model is solved by GA with generation size 100. The run-time of the GA rises with the generation size. But the results vary nominally. The population size is 100, which means 100 Z_{min} results are generated in every generation, and the mean of 100 results is shown along with the best result in every generation. The Z_{min} (average) is the mean of 100 results and the Z_{min} (best) is the lowest amount of results in each generation. Figure 6.2 shows the vector entries of the best individual with the best fitness function value in each generation. Figure 6.3 shows the genealogy of individuals. Lines from one generation to the next are color-coded as follows: red lines indicate mutation children, blue lines indicate crossover children and black lines indicate elite individuals. Figure 6.4 shows the minimum, maximum and mean fitness function values in each generation.

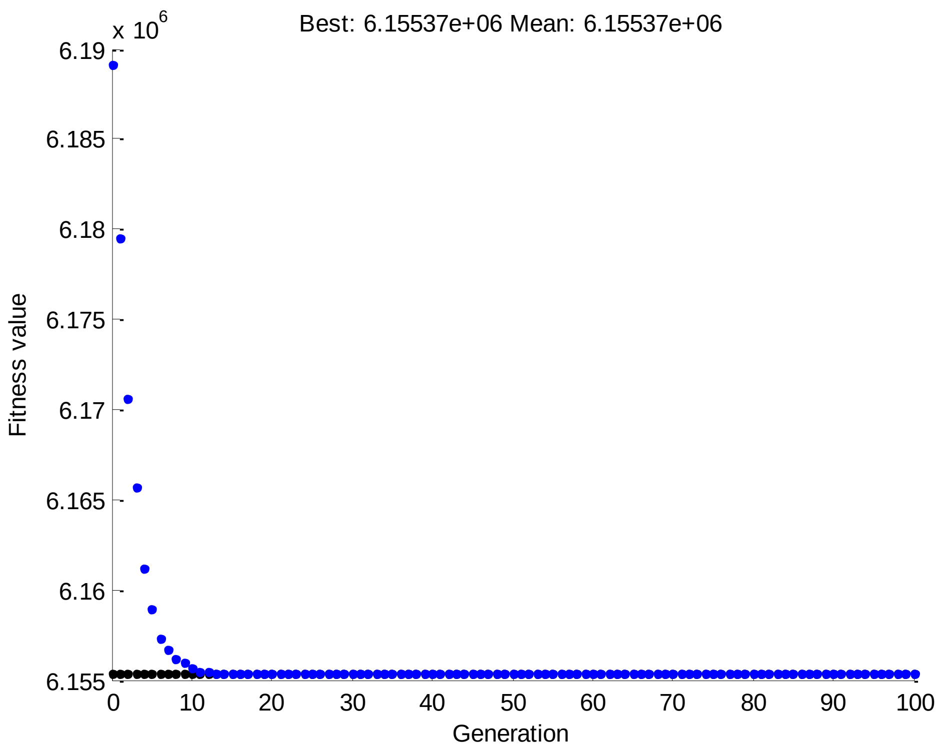

Figure 6.1: Best and mean function value of Z_{min}

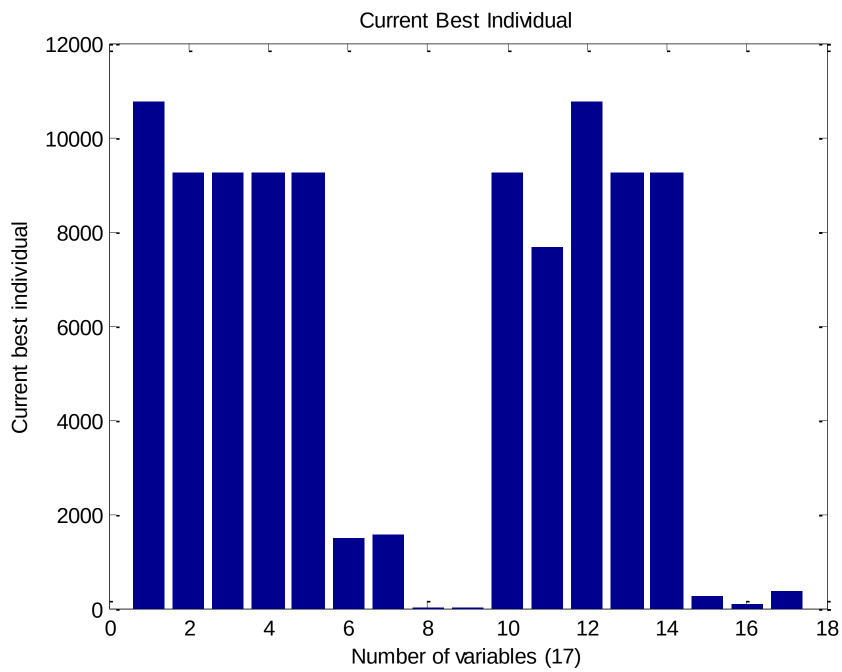

Figure 6.2: Best individual with the variables

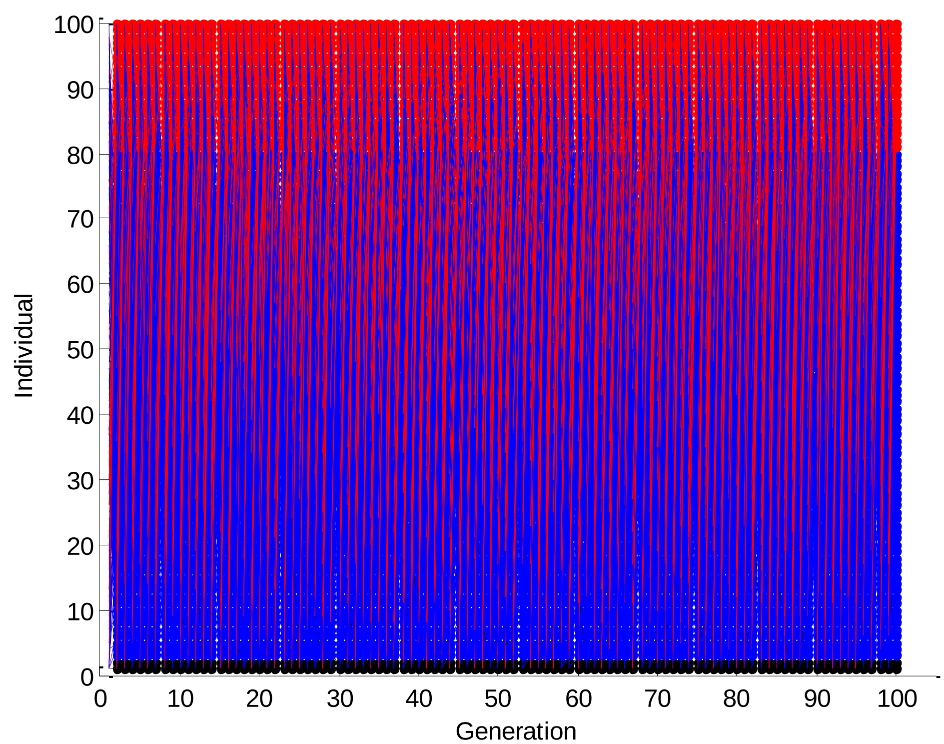

Figure 6.3: Genealogy of individuals

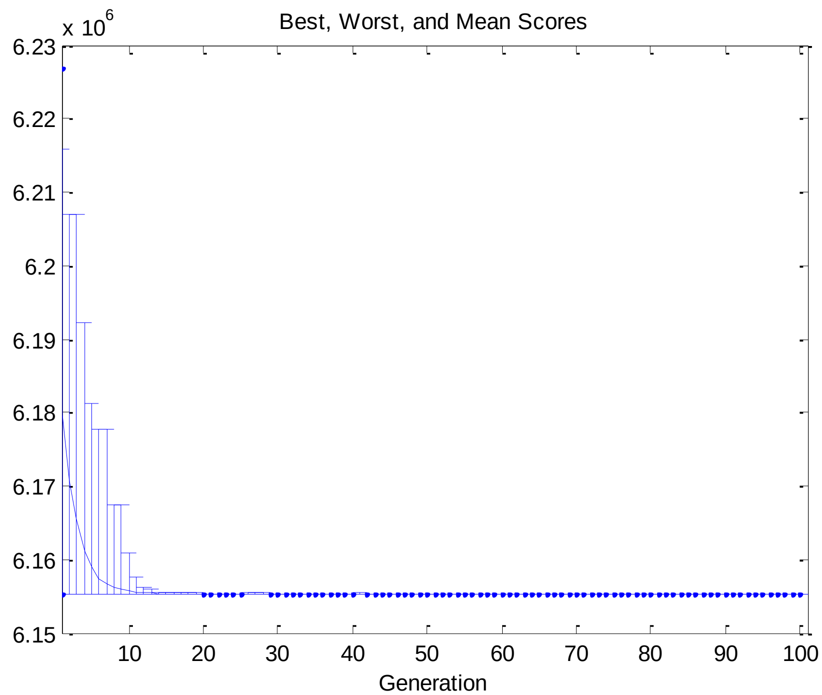

Figure 6.4: Min, max and mean values of Z_{min}

6.4 Sensitivity Analysis

In this study, Sensitivity analysis is used to identify the importance of various parameters to evaluate the sensitivity of the model output. This tool is used here to analyze how the different values of a set of independent variables affect a specific dependent variable under certain conditions. It allows to assess the results and to identify the inputs whose variations have an impact on the outputs. This study helps to understand how the unpredictability in the output of a mathematical model or system can be divided and allocated to different sources of unpredictability in its inputs. It, also known as a What-If analysis, is most commonly used in different financial analysis to predict the outcome of a specific action when performed under certain conditions. It is done within defined boundaries that are determined by the set of input variables.

This method is used in this study to determine the robustness or consistency of the behavior of the model under different methods, variables or assumptions. It is a re-analysis of the same outcome using different approaches and definitions of the outcome with the aim of assessing how these changes impact the conclusions. Sensitivity Analysis adds credibility to the model by testing the model across a different set of possibilities. Supply chain-2 (SC-2) is considered here that manufactures apparel products not considering rework of defective goods. It is the process of recalculating outcomes under alternative assumptions to determine the impact of a variable. In this study, the sensitivity results for different parameter bounds like capacity of manufacturers, EPQ, amounts of defective goods and time required to rework the defectives are compared. The amount of Economic Production Quantity varies according to the production capacity for manufacturer at a certain time period under the SC-1(C_{mnt}), Pcs/month (26 days) that shows the following figure 6.5.

Table 6.23: EPQ vs. Capacity analysis

Capacity of Manufacturers	EPQ
22000	11627.91
20000	10752.69
18000	9677.419
16000	8602.151
14000	7526.882
12000	6451.614
10000	5376.344
8000	4301.075
6000	3225.806

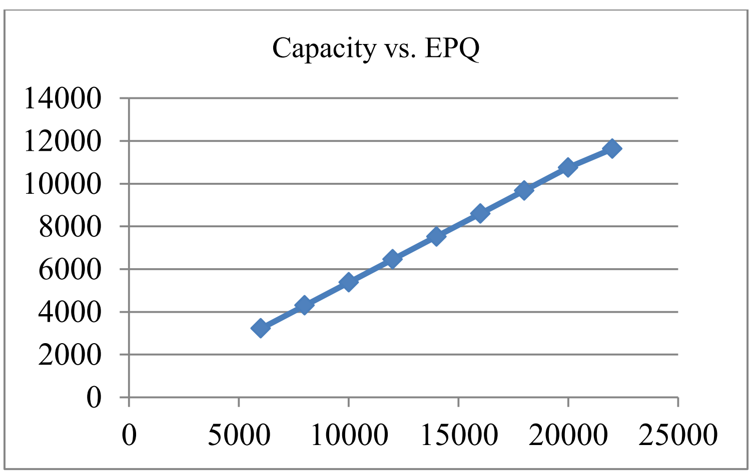

Figure 6.5: Capacity vs. EPQ analysis

The amount of defective goods produced by manufacturer varies according to the Economic Production Quantity at a time period under the SC-1 Pcs/month (26 days) that shows the following Figure 6.6. These results show that, although each parameter‟s sensitivity index changed, the main ranking of parameter sensitivity was marginally influenced by the parameter bounds. This result is consistent with the study of the model in that the impact of various parameter bounds on the parameter is very small, even when the upper and lower limits of the parameter ranges are considered.

Table 6.24: EPQ vs. Defectives analysis

EPQ	Defective d_{111}
11627.9105	1627.907
10752.6883	1505.376
9677.41894	1354.838
8602.15065	1204.301
7526.8821	1053.763
6451.61354	903.2255
5376.34406	752.6872
4301.07491	602.1504
3225.80598	451.6121

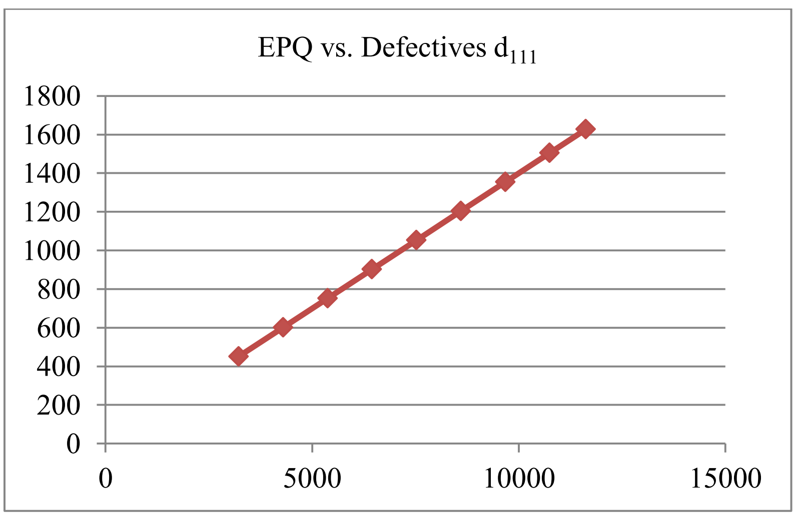

Figure 6.6: EPQ vs. Defectives analysis

This section proposes a framework of sensitivity analysis for the primary data aiming at the consistent and robust identification of important parameters and assumptions. The comparative results provided in this study also can support the assessment and interpretation of the results. Some parameters‟ sensitivity grows under fluctuations of the assumed values, whereas some decreased according to the inputs. This exposes the effect of the model output on the variations of each input parameter. In general, the results confirmed that the parameters‟ boundaries could be avoided when choosing the optimum parameters. The amount of time (hr.) required to rework by manufacturer varies according to the amount of defective goods produced by the manufacturers at a certain time period under the SC-1 hr./pcs that shows the following figure 6.7.

Table 6.25: Defectives vs. Rework time (hr.) analysis

Total defective	Total Rework time (hr.)
3391.16218	88.16278
3077.41908	78.60297
2769.67696	70.74272
2461.9352	62.89028
2154.19286	55.02239
1846.45107	47.16038
1538.7085	39.30262
1230.9675	31.44478
923.224853	23.63533

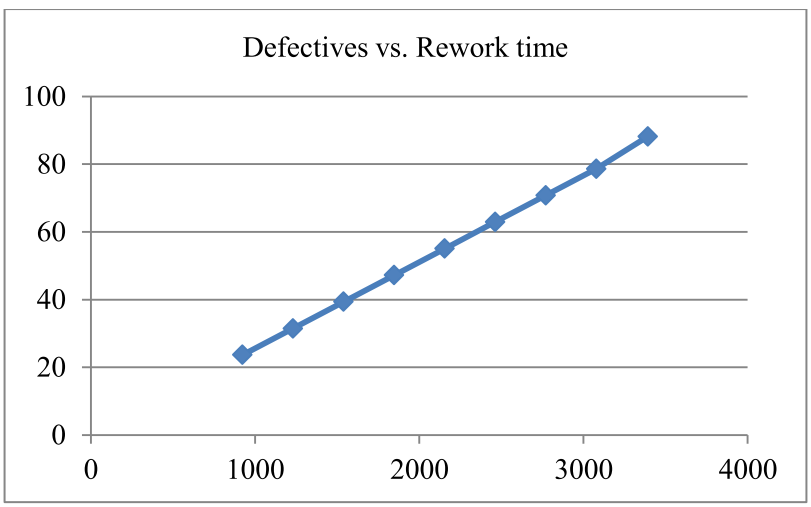

Figure 6.7: Defectives vs. Rework time (hr.) analysis

6.4.1 Supply chain 2: T-shirt manufacturing (YAL)

The company considered here for supply chain 2 is a manufacturer of T-shirts and Polo shirts. The manufacturer is a one-stop solution provider that has also a development department. The manufacturer is part of a global supply network with suppliers from all over the world. The customers of the manufacturer are organizations within the group organizing the distribution in different markets.

An overview of Y Apparel Ltd.: Y Apparel Ltd. is one of the vertical companies in apparel arena in Bangladesh. It features in the world"s top fashion outlets. YAL"s horizon is painted with platinum for its friendship with the mother earth. This readymade garments producer which is aligned the vision with Bangladesh, the most popular country as an apparel manufacture on the entire planet. It is one of the largest one-stop solution providers of garments for leading apparel brands around the world.

6.4.1.1 Analysis of Total Supply Chain Cost function

Table 6.26 depicts that the total supply chain cost. The decision maker can choose any value from this range of costs trading off the corresponding values of the other variables and constraints. The developed model is solved seven times by the GA to demonstrate the performance accuracy using the same parameter from the tables presented earlier. The results are slightly divergent because of choosing the statistical distributions for the values of the parameters. The values of Z_{min} of each run from the GA are illustrated in Table 6.26. Additionally, the best output of the solution (out of seven runs) is presented in Table 6.27.

Table 6.26: Value of objective functions Z_{min}

Run	Run 1	Run 2	Run 3	**Run 4**	Run 5	Run 6	Run 7
$\mathbf{Z_{min}}$	2673688.73	2673688.72	2673688.72	2673688.72	2673688.73	2673688.74	2673688.72

6.4.1.2 Analysis of decision variables for a set of solution

At this stage of analysis a set of solution has been elaborated with the values of 17 decision variables. This solution set has been taken from the GA generated in run 5. The optimum costs, amounts of Economic Production Quantity, defective goods, perfect goods of the supply chain-2 for run 5 are shown in Table 6.27. As the total length of each period is limited to the sum of total production time and total rework time by the manufacturers, any change in the production and rework time has a direct effect on the production rate. The model searches for the best path using the parameters to get the optimum values of the variables that are shown in Table 6.27 for the run 5. In addition, the required production time to fulfill the retailer demands. The model suggests that with the increments in the production and rework times, the total costs decreased.

Table 6.27: Value of decision variables for a set of solution (run 4)

Variable	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7
X_1	10052.910	10052.910	10052.910	10052.910	10052.909	10052.910	10052.910
X_2	9947.089	9947.089	9947.089	9947.089	9947.090	9947.089	9947.089
X_3	9449.735	9449.735	9449.735	9449.735	9449.735	9449.735	9449.735
X_4	9449.736	9449.735	9449.736	9449.735	9449.736	9449.735	9449.736
X_5	9449.736	9449.734	9449.735	9449.735	9449.735	9449.735	9449.736
X_6	402.116	402.115	402.116	402.115	402.115	402.116	402.115
X_7	497.353	497.353	497.354	497.354	497.353	497.354	497.353
X_8	402.116	402.115	402.115	402.115	402.115	402.116	402.115
X_9	497.353	497.353	497.353	497.353	497.353	497.353	497.353
X_{10}	9449.735	9449.736	9449.735	9449.735	9449.735	9449.735	9449.735
X_{11}	9449.736	9449.735	9449.736	9449.735	9449.735	9449.735	9449.735
X_{12}	9449.736	9449.736	9449.735	9449.735	9449.735	9449.736	9449.735
X_{13}	9449.736	9449.736	9449.736	9449.736	9449.736	9449.736	9449.735
X_{14}	9449.735	9449.735	9449.735	9449.735	9449.735	9449.735	9449.735
X_{15}	201.058	201.078	201.058	201.058	201.121	201.058	201.058
X_{16}	0.000	0.070	0.000	0.000	0.000	0.237	0.000
X_{17}	201.058	202.058	201.058	201.058	202.068	202.574	201.120

Here, $X_1 = q_{111}$, $X_2 = q_{211}$, $X_3 = X_{111}$, $X_4 = Y_{1111}$, $X_5 = X_{2111}$, $X_6 = d_{111}$, $X_7 = d_{211}$, $X_8 = Sr_{111}$, $X_9 = Sr_{211}$, $X_{10} = n_{111}$, $X_{11} = n_{211}$, $X_{12} = N_{111}$, $X_{13} = N_{211}$, $X_{14} = r_{111}$, $X_{15} = Ta_t$, $X_{16} = Tb_t$, $X_{17} = Tt_t$. Figure 6.8 shows the curves for Z_{min} (best) and Z_{min} (average) for run 5. It plots the best function value in each generation with respect to iteration number. The model is solved by GA with generation size 100. The run-time of the GA rises with the generation size. But the results vary nominally. The population size is 100, which means 100 Z_{min} results are generated in every generation, and the mean of 100 results is shown along with the best result in every generation. The Z_{min} (average) is the mean of 100 results and the Z_{min} (best) is the lowest amount of results in each generation. Figure 6.9 shows the vector entries of the best individual with the best fitness function value in each generation. Figure 6.10 shows the genealogy of individuals. Lines from one generation to the next are color-coded as follows: Red lines indicate mutation children. Blue lines indicate crossover children. Black lines indicate elite individuals. Figure 6.11 shows the minimum, maximum and mean fitness function values in each generation.

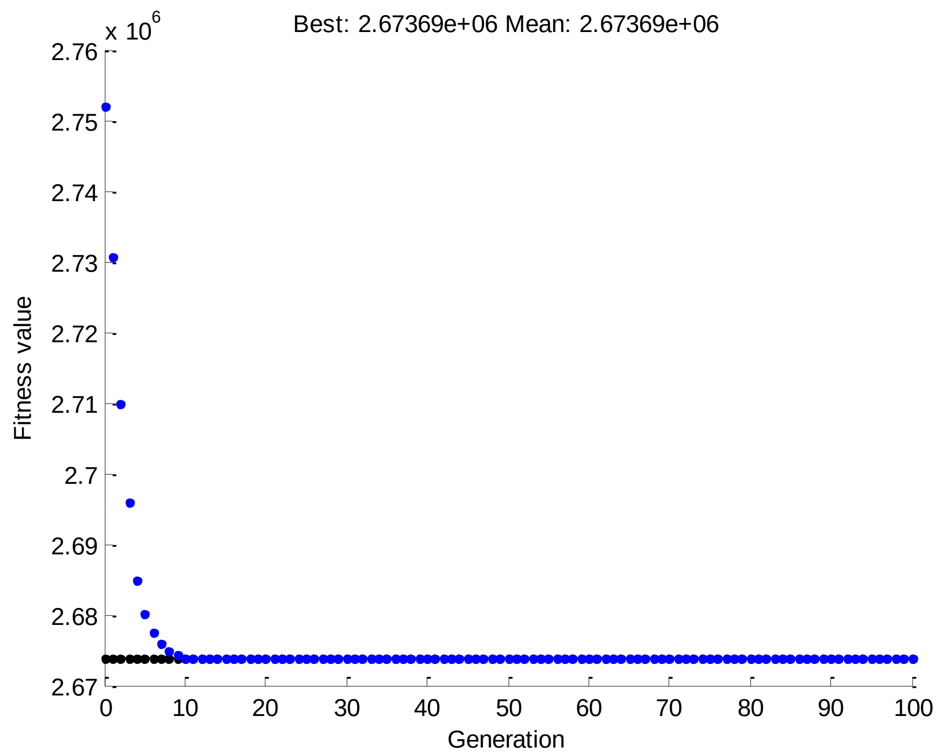

Figure 6.8: Best and mean function value of Z_{min}

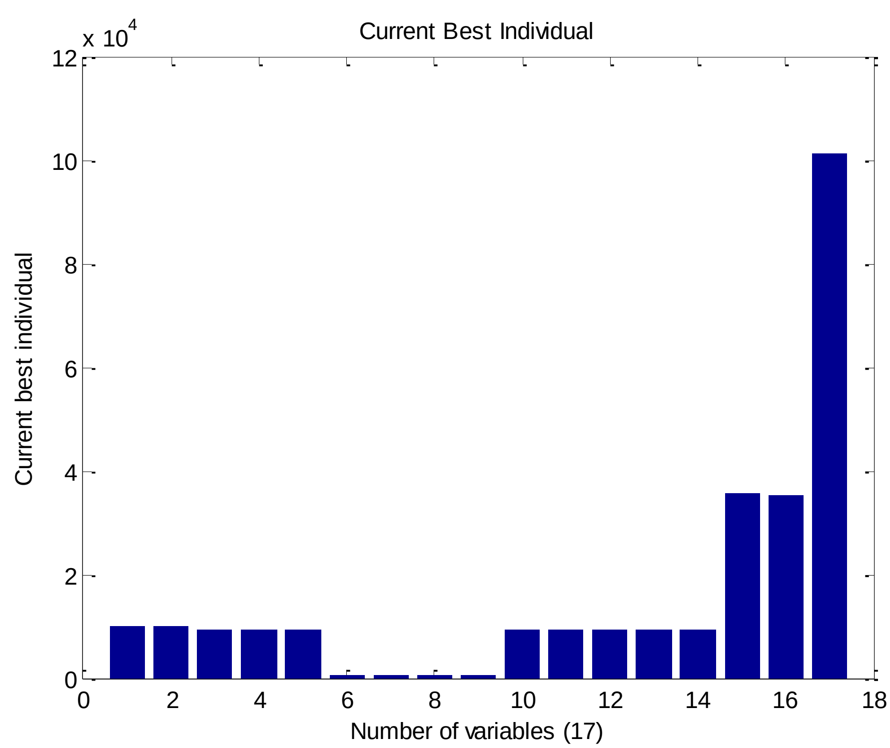

Figure 6.9: Best individual with the variables

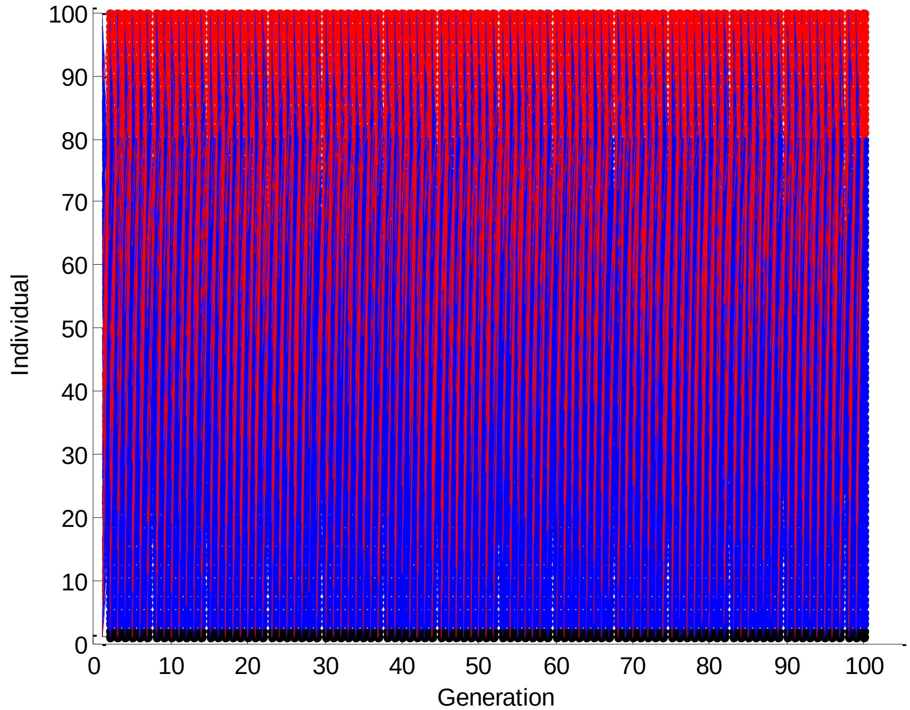

Figure 6.10: Genealogy of individuals

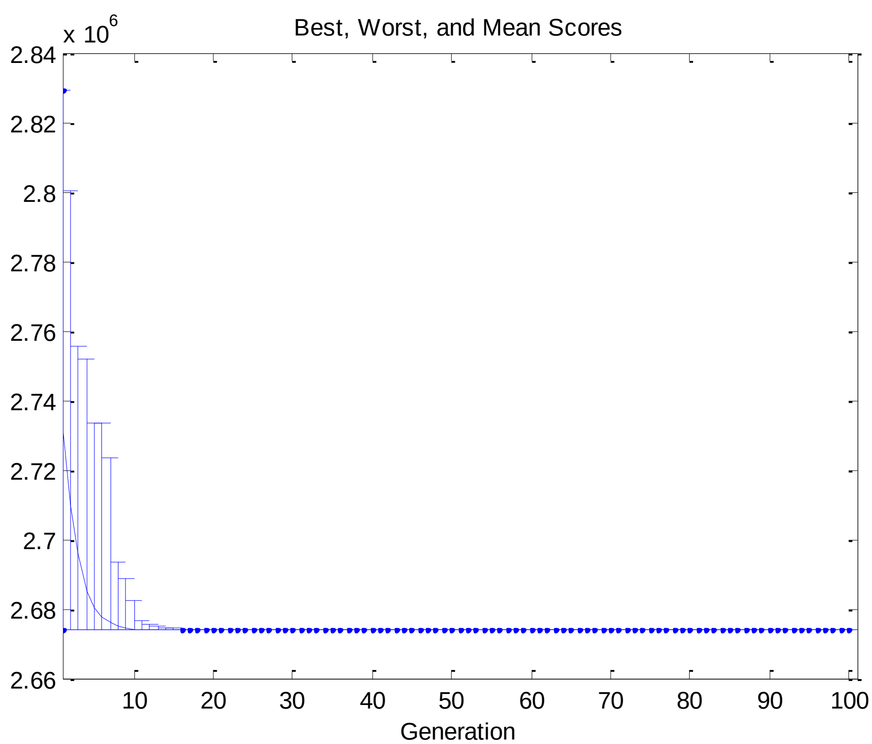

Figure 6.11: Min, max and mean values of Z_{min}

6.4.2 Model Validation

Model validation is a crucial part of any modeling activity. Verification and validation is an important approach in ensuring the credibility of the modeling [75]. It refers to ensuring that a model is an accurate representation of the real system. This study also does not depend on an individual solver for the accuracy of the model. In this section, several set of solutions is compared with that of LINPROG in order to demonstrate and validate the optimization model equations and their behavior.

Table 6.28: Comparison between GA and LINPROG results (Z_{min})

Run	Supply Chain 1		Supply Chain 2	
	Z_{min}		Z_{min}	
	GA	LINPROG	GA	LINPROG
1	6155365.380	6155365.699	2673688.727	2673594.392
2	6155365.383	6155365.699	2673688.722	2673594.392
3	6155365.390	6155365.699	2673688.724	2673594.392
4	6155365.386	6155365.699	2673688.723	2673594.392
5	6155365.381	6155365.699	2673688.725	2673594.392
6	6155365.385	6155365.699	2673688.739	2673594.392
7	6155365.384	6155365.699	2673688.718	2673594.392

The representations in Table 6.28 show the validity and accuracy of the model and the GA. The validation tests aim to ensure the validity of the structure and the correctness of the outcomes of the model. The test evaluates whether the structure and the logic of the model mimics the corresponding structure and logic of the real world process. The model validity is gradually enhanced through the process by progressively building confidence in the usefulness of the model by applying validation tests in different phases of the model development. However, models are seldom compared or validated with real cases, the results ensure the usability of it for any logical changes in that particular area [76]. As discussed in Chapter 2 & 3, this test is executed iteratively throughout the modeling process where the model behavior and outcomes where continuously validated by the expert group through their knowledge about the system and their knowledge about internal supply chain, manufacturing and production theory concepts.

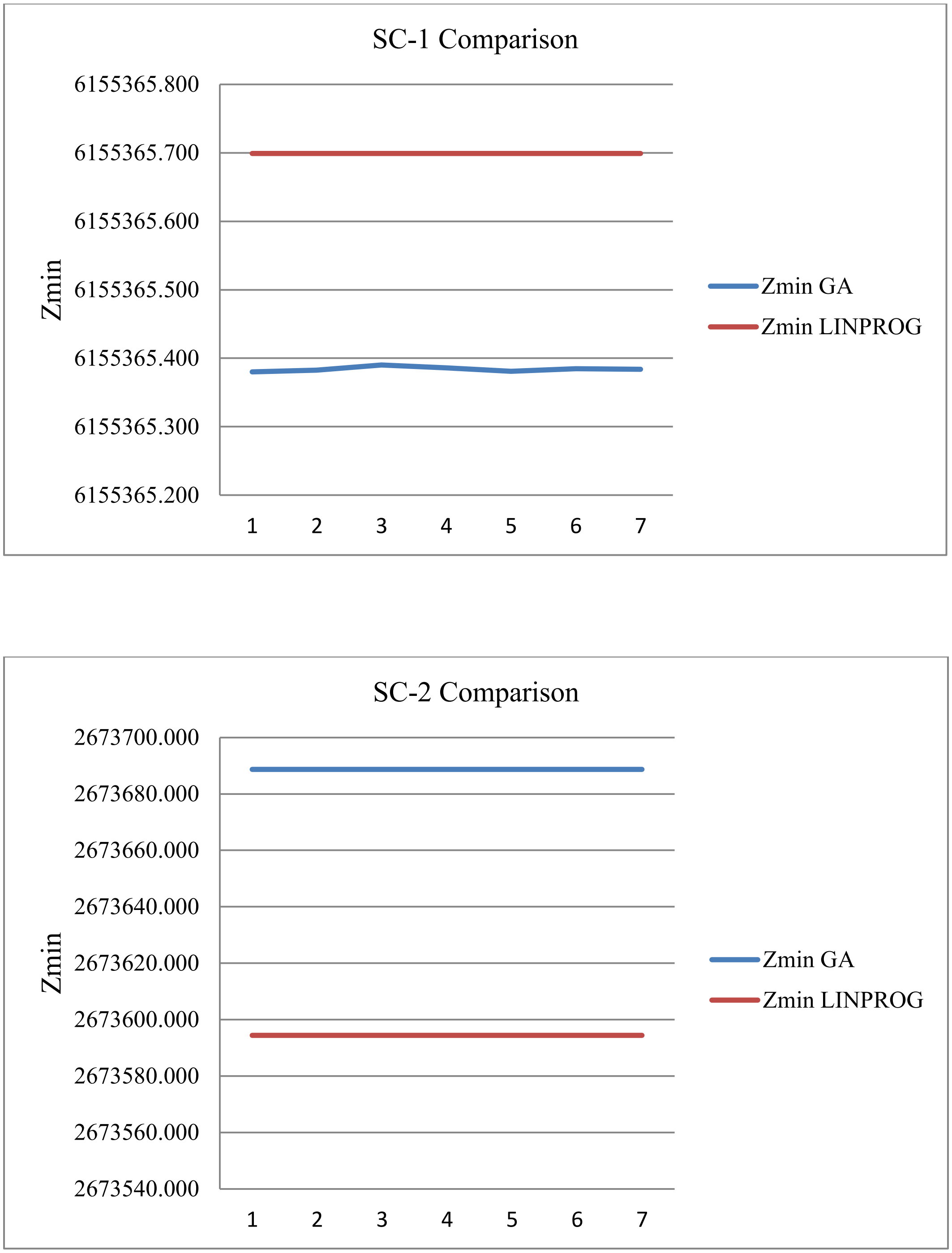

Figure 6.12: Comparison between GA and LINPROG results (Z_{min})

CHAPTER 7

CONCLUSION AND FUTURE RESEARCH

This chapter presents the overall conclusions of the research carried out in this study. Finally, the chapter provides some thoughts on future work, based on the research conducted in this thesis.

7.1 Conclusion

Supply Chain Management has a wide scope and it includes a lot of theories about how to set up the chain. This research does not go into details regarding everything included in the term Supply Chain Management. The motivation of this research is to develop a new model for defective goods supply chain cost optimization of which has the goal of fulfilling and grasping some new research opportunities in the field of supply chain cost optimization.

In general, supply chains are complex networks composed of autonomous entities where multiple costs at different levels, which in most cases are in conflict with each other. Due to these multiple costs, SC decision making is much more complex than treating it as a single objective optimization problem. Therefore, this work addresses the SC optimization problem addressing different types of costs considering and without considering the rework in order to capture its dynamic behavior. After a comprehensive literature review, research gaps in the field of defective goods supply chain network cost optimization is identified and the objectives for the research design are formed. The proposed model is formulated with an objective function that is to optimize the total supply chain cost. The model is applied to two real-world supply chains with different value streams for proving its functionality and furthermore analyzing the outcomes from the optimization. During this work a lot of time have been spent to explore an innovative model and advanced solving methodologies. Genetic Algorithm has been chosen to apply in this model because of its usability, availability and high probability of reaching the global optimum. Moreover the GA is quick to implement and the concept is very easy to understand in practice. The solutions are compared with that of LINPROG in order to demonstrate the model, equations and their behavior.

The analysis results provide strong indications that the methodology, model and techniques introduced in this thesis are capable to generate knowledge to support academic SCM research and real-world SCM decision making. Proper required index, parameters, and variables have been introduced and added more flexibility to the model implementation. In addition, the service costs and the possibility of shortage of materials at the delivery stage of supply chain (semi-finished part or finished part) have been taken into account in the model of this study that makes the model more realistic. Different viable data and sources enable the assembly of the model and provide more transparency of the results. In this research, the model is provided with the objective function of total costs minimization to result in not only the EPQ but also the impacts of imperfects goods on total SC cost. Sensitivity analyses of this study play an important role in assessing the robustness of the findings or conclusions under different assumptions, methods or scenarios. It provides an evaluation of the confidence and credibility in the model and strengthens the conclusions of the findings. It allows the analyst to be flexible with the boundaries and helps the decision makers to understand how responsive the output of the model is to changes in certain variables. It also enhances the communication from analyst to manufacturer to make optimal decisions. Although this model is tested by steel and apparel companies, it can be extended to be applicable in any other business to identify the most cost-effective approach. Thus, the applications of it are not limited to specific stages or levels of the chain. That shows that this work can be implemented to assist companies in making better informed decisions on the design and implementation of its manufacturing. The manufacturers can make incremental changes to existing operational processes based on the study's general findings. It validates the model as a valuable decision making tool.

Lastly, even though this new model has some limitations, the applications of it can be found in the area of supply chain cost management and in designing an optimum supply chain network. Moreover it has become the platform for the researcher that unearths some interesting scopes for further research in this particular area. Besides being a model dedicated to strategic supply chain designs, with certain modifications it can be used for optimizing or restructuring existing supply chain costs. It is supposed to be an engineering and management tool, rather than being a scientific one. Therefore, global corporations with robust supply chains, who are tending to focus of optimizing the overall SC performances in terms of cost, time and quality (perfect & defective) can definitely benefit from this research.

7.2 Recommendations for future research

In concluding the thesis, this section proposes some future research directions, based on the results obtained from the studies conducted in the thesis. The research describes the successful implementation of the model on two real world supply chains, which generated the desired solution sets for each case and well provided insight into the system costs optimization. However, despite the successful implementation, there are a number of ways that the research done in this thesis can be improved further in future in this particular area.

- Regarding the limits of the research, two supply chain cases are tested and the supply chain structures are relatively small. However, for the initial testing of this model presented it is satisfactory, it may be tested to a dedicated case example in broader/global sense. Moreover, it can be evaluated through time-concentrated strategies, such as just-in-time (JIT) philosophy, quick response production, and flexible manufacturing in order to further the understanding of supply chain efficiency.

- This study has presented couple of industrial application, which cannot be seen as a representative for all companies. This model can also be extended to other price-sensitive, time-sensitive and quality sensitive business like food, telecom, paper, ceramics, cement, car industry, construction industry and others. The selection of the logistics variables and parameters can be modified for use in the process selection or other types of selection as it has the same concept, just different criteria and related costs.

- One of the most interesting additions of this developed model is service cost. This area has a great potential for improvement in the defective goods supply chain like hotels or restaurants, online delivery, furniture etc. Here more in-depth studies have to be performed in order to increase the understanding of this particular cost. Thus, this specific area could be further developed by more influences from literature about costs and services simultaneously.

- The model is currently limited to the retailer excluding the customer in the chain due to the absence of some required data. Again, by enhancing the visibility and control of the stages in the chain, the model can be applied for each specific part from its starting point until the end of the chain. Furthermore, by increasing the accessibility of the data, the cost of shortage of semi-finished or finished part can be more accurate by adding and re-sequencing the cost of manufacturing.

However, from a modeling point of view, applying the model and testing it with real case data is an important phase that confirms the findings and search for new potential ones. As a last step, studying in-depth genetic algorithms and developing a specific one for solving this kind of problems is an important challenge. Along with this, new tools and methods for analyzing big data from GA‟s solutions generations should be developed with other solver like Particle Swarm based optimization (PSO). These future improvements are significant to step forward in the defective goods supply chain cost optimization for different companies, which will certainly improve the models and will aim at identifying new trade-offs.

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