REDUCTION OF BULLWHIP EFFECT IN A SUPPLY CHAIN USING GENETIC ALGORITHM

By

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE IN INDUSTRIAL AND PRODUCTION ENGINEERING

DEPARTMENT OF INDUSTRIAL AND PRODUCTION ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DHAKA- 1000, BANGLADESH

AUGUST, 2009

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Tahera Yesmin

ACKNOWLEDGEMENT

My gratitude earnestly goes first to benevolent Allah, the beneficial, the merciful. I thank the Almighty for giving me the strength to come up so far in my life. Moreover, I thank the Almighty for making me able to complete this work.

I express my intense thankfulness to my thesis supervisor Dr. Md. Ahsan Akhtar Hasin, Professor of the Department of Industrial and Production Engineering, for his constant help, guidance, encouragement and valuable suggestions through the course of this thesis work.

My appreciation also goes to Dr. A. K. M. Masud, Associate Professor, Department of IPE, BUET, Dr. Sultana Parveen, Assistant Professor, Department of IPE, BUET and Dr. Dilip Kumar Roy, Senior Research Fellow and Chief, General Economics Division, Bangladesh Institute of Development Studies (BIDS), for their kind support, time and interest in this research.

My strong thankfulness goes to Nuruddin Ahmed Bappy, under graduate student, department of C.S.E., BUET, for his time to computer code this thesis.

I am also very grateful to the management of Nestle Bangladesh Ltd. and Nandon for their kind support and time.

I would like to thank Mr. Ferdous Sarwar, Selina Begum and Farhana Rahman for their valuable support from abroad.

I also appreciate the support and cooperation of all my friends and colleagues especially to Annaya Chanda Shimi, Lecturer, Department of URP, BUET and to Farhana Afreen Proma, Lecturer, Department of IPE, BUET for their strong support and help.

Finally, I would like to thank my parents, my husband and family members for being so considerate and caring. Without their continuous support and warmth this work would not have been completed.

ABSTRACT

In a supply chain a number of various business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together in an effort to acquire raw materials, convert these raw materials into specified final products, and to deliver these final products to retailers. Supply chain activities begin with a customer order and end when a satisfied customer has paid for the purchase. Bullwhip effect of supply chain refers to the amplifications in orders in the supply chain. Industries with reliable demand forecasts waste million of dollars every year because they are not able to match the production to demand. As a consequence of this demand variability bullwhip effect results which leads to the inefficiencies in supply chain like quality problem, overtime expenses, missed production schedule, inventory problem. poor customer service, higher raw material cost, shipping cost, inventory cost, distribution cost, however an overall rise of the total supply chain cost. This research intends to reduce bullwhip effect in a supply chain by finding the optimal ordering quantities for each member of the supply chain. This research used genetic algorithm with an objective function to minimize the total supply chain cost by calculating total costs for each of the supply chain member. The objective function developed for the algorithm contains maximum five different types of costs for each of the supply chain members. Later, the proposed algorithm was applied to analyze a case which is a complex supply chain containing three retailers, one distributor, one warehouse and a factory. A simulation was conducted to find the existing ordering quantities for the case which was then compared with the results obtained from genetic algorithm. In this research various parameters of genetic algorithm were used and two different sets of analysis were conducted by changing the parameters mainly the chromosome range. Finally. the results obtained from genetic algorithm reduced the total supply chain cost of the considered case and thus found the optimal ordering quantities which minimized the bullwhip effect from the supply chain. It was also shown from the results of both the analysis of genetic algorithm that optimal ordering quantities found with the lower range of chromosomes reduced the bullwhip effect by lowering the supply chain cost even more.

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GA	Genetic Algorithm
TSCC	Total Supply Chain Cost
CO	Cross Over
SP	Selection Pressure
SC	Supply Chain

NOMENCLATURE

M	number of weeks
Z	total cost considering costs for each member
p_c	crossover rate
p_m	mutation rate
p_i	probability
q_i	cumulative probability
N_{cp}	number of cross over points
$INVC_i$	inventory holding cost for member i.
H_i	inventory unit holding cost price for member i.
BKC_i	back order cost for member i.
UFD_i	back orders for member i
B_i	backorder unit cost price for member i
OC_i	ordering cost for member i
R_i	ordering cost for member i
O_{ij}	order from member i for member j.
a_{ij}	unit shipping cost from member i to member j
b_i	unit price of the item for member i
x_{ij}	number of units distributed from member i to member j
VC_{ij}	cost of per cargo shipping from member i to member j
Q_i	cargo capacity of the member i.
PC_i	production cost for factory
D_{ij}	demand that member j receives from member i.
CU_i	production unit cost price for member i at week

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

Intense competition in global markets, the shortening of product life cycles and the increased expectations of customers. have focused businesses attention on the need to invest in their supply chains. At the same time, improvements in communications and transport technologies have provided a major impetus for the continuous evolution of the supply chain and of the techniques to manage it. Attempting to match the supply of products with consumer demand is extremely difficult. As product variety has increased firms have reacted by increasing inventory carrying costs, markdowns and write-offs due to excess inventory.

For a typical supply chain, materials are procured which are then produced into items at one or more manufacturing facilities. Subsequently, the finished products are shipped to distribution centers for storage, before being shipped on to retail outlets for sale to the end customer. An effective supply chain strategy needs to facilitate the interactions at the various stages in the chain. In managing a supply chain a holistic approach is required to ensure that it is both efficient and cost effective across the whole system. Thus, the emphasis is not on simply minimizing the costs for a specific entity, but rather on taking a systems approach to reduce the cost for the overall supply chain.

The pace of change and the uncertainty about how markets will evolve has also made it increasingly important for companies to be aware of the supply chains they participate in and to understand the roles that they play. Those companies that learn how to build and participate in strong supply chains will have a substantial competitive advantage in their markets.

The effective management of the supply chain requires close integration between the various stages involved in the delivery of the product to the consumer. An important element in this is the information on demand. This requirement is used by each entity in the supply chain for production planning and control purposes. However, with the aggregation of demand information, distortion occurs as it passes upstream and moves away from the end consumer. This demand variation has become referred to as the bullwhip effect [1, 2].

Bullwhip Effect is a problem in forecast-driven supply chains, and careful management of this effect is an important goal for Supply Chain Managers.

1.2 BACKGROUND OF THE STUDY

Businesses today are not separate entities; they are all working together in one supply chain, which can improve the quality of goods and services across the supply chain. Each stage in the supply chain need to perform a different process and must interact with all other stages in supply chain. The primary purpose of a supply chain is to satisfy the needs of the customer while generating profits.

Bullwhip effect refers to the amplifications in orders in a supply chain. Industries with reliable demand forecasts waste millions of dollars every year because they are not able to match production to demand. The bullwhip effect is a major cause of the problem. Procter & Gamble [1] were one of the first companies to discover the bullwhip effect when they examined the ordering patterns for one of their products. The retail demand was fluctuating slightly, but when examining the upstream members of the SC, there was a greater variability of orders [2].

This distorted information from one end of the supply chain to the other can lead to inefficiencies, i.e. excessive inventory, quality problems, higher raw-material costs, overtime expenses, shipping costs, poor customer service, and missed production schedule [2].

Effective supply chain has already played a very important and significant role in the business area of all over the world. It has always been a very popular topic for the industries and researchers of the developed countries to conduct more and more researches to make their supply chain more efficient, but for a developing country like Bangladesh it is a newly emerging concern of the industries and there from the author came up with this research.

In order to reduce bullwhip effect in supply chain researchers have used many concepts mainly classical management techniques which include the information sharing and forecasting mainly. Very few researchers like Kimbrough et al. [3] used artificial intelligence to solve the problem of bullwhip effect but not for a real supply chain which also drove the force for this research.

However, this research is mainly aimed to study the supply chain in an industry which is running in Bangladesh. It is conducted to find an optimal ordering policy which will reduce bullwhip effect for the industry studied. To find the optimal ordering policy for every member of the supply chain, computer intelligence technique genetic algorithm is used. Genetic algorithm will search exhaustively for the global optimum ordering policy and allocate this ordering policy to each member of the supply chain. This research mainly investigates whether the optimal ordering policies for each member of a supply chain can be found using a genetic algorithm which will reduce the bullwhip effect and cost across the entire supply chain.

1.3 OBJECTIVES OF THE STUDY

The ultimate objectives of this study are the followings,

i. Based on different theories study and analyze the history of the evolution of the concept of bullwhip effect and the main causes responsible for this in a supply chain which are described in details in chapter 2 and in the following chapter 3.

ii. Search for a computer intelligent technique which has the ability to reduce the bullwhip effect and to mitigate its consequences like excessive costs of a supply chain.

iii. Study the system of supply chain and develop an algorithm to reduce the bullwhip effect.

1.4 OUTLINE OF METHODOLOGY

i. Identification of the search technique which can reduce the bullwhip effect in a supply chain.
ii. Development of the objective function for genetic algorithm to determine the reduction of bullwhip effect.
iii. Determining the key elements and parameters for the genetic algorithm.
iv. Development of the algorithm which can minimize the objective function.
v. Study the case and determine all the parameters need to complete the algorithm.
vi. The performance of the algorithm is then measured by the case study.
vii. An extensive analysis of the algorithm by changing the parameters is conducted to find the best optimum ordering policy.

1.5 POSSIBLE OUTCOMES OF THE STUDY

The possible outcomes of the research are the followings,

i. Optimal ordering quantities for all the members of a supply chain which will reduce the bullwhip effect as well as the overall supply chain costs.
ii. An algorithm with suitable parameters for the system which will reduce bullwhip effect.

1.6 LIMITATIONS OF THE STUDY

Supply chain is a very complicated system. It includes many parameters and involvement of many people to run a supply chain effectively [4]. The supply chain model used here depicted a simplification as one industry has hundreds of products, if not thousands, but hundreds of retailers and suppliers. As a consequence the supply chain becomes very huge. The supply chain for a single product is considered in this research. Since the product considered here is supplied all over the country to a thousand of retailers, it is not possible to collect the data for the research in such extensive level with limitations like sources of information and cooperation. A limited but an important portion of customer region is considered to conduct the study and to find whether genetic algorithm can be used to reduce the bullwhip effect. The more the members are included in the model, the more the realistic policy would be found with the help of genetic algorithm. Thus by including more and more members and information of the supply chain, this limitation can be conquered.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

Recently there has been a surge of interest and research on the phenomenon popularly called the bullwhip effect. This phenomenon refers to the amplification in orders in a supply chain which indicates that the demand process seen by a given stage of a supply chain becomes more variable as one moves up the supply chain (i.e. as one moves away from customer demand). In other words orders seen by the upstream stages of a supply chain are more variable than the orders seen by the downstream stages. Numerous researches have paid their attention to analyze bullwhip whip effect. Some of the areas of focus of the previous researches are [5].

a. Providing empirical evidence supporting the existence of the bullwhip effect.
b. Analytically demonstrating the existence of the bullwhip effect.
c. Identifying the possible causes of the bullwhip effect and
d. Developing strategies to reduce the impact of the bullwhip effect.

2.2 HISTORY OF BULLWHIP EFFECT

The phenomenon named bullwhip effect has its origins in system dynamics theory developed by Forrester [6] where, in many cases, the variance in perceived demand for a manufacturer was several orders of magnitude larger than consumer demand. In addition, Forrester identified that this amplification effect occurred at each stage in the supply chain. One of the major factors which caused the bullwhip was that the information feedback loop between companies was too complex for managers to resolve intuitively. Forrester proposed that the only way to resolve these complex supply interactions was to treat the supply chain as a complete system. Managers could then model the complete system to determine the appropriate action to be taken.

In an inventory management experimental context, Sterman [7] reports the evidence of bullwhip effect in the "Beer Distribution Game". The experiment involves a supply chain with four players who make independent inventory decisions without consultation with other chain members, relying only on orders from the neighboring players as the sole source of communications. The experiment shows that the variances of orders amplify as one moves up the supply chain, confirming the bullwhip effect.

Later. Lee et al. [1, 2] shows that a number of major companies also faced problem due to the bullwhip effect. Procter and Gamble were one of them. Logistics executives at Procter & Gamble (P&G) examined the order patterns for one of their best-selling products, Pampers. Its' sales at retail stores were fluctuating, but the variability was certainly not excessive. However, as they examined the distributors' orders. the executive were surprised by the degree of variability. When they looked at P&G's orders of material to their suppliers, such as 3M, they discovered that the swings were even greater. At first glance, the variability did not make sense. While the consumers, in this case, the babies, consumed diapers at a steady rate, the demand order variability in the supply chain were amplified as they moved up the supply chain. P&G then called this phenomenon the "bullwhip" effect.

Again when Hewlett-Packard (HP) [2] executives examined the sales of one of its printers at a major reseller. they found that there were, as expected, some fluctuations over time. However. when they examined the orders from the resellers, they observed much bigger swings. Also, to their surprise, they discovered that the orders from the printer division to the company's integrated circuit division had even greater fluctuations.

In the past, without being able to see the sales of its products at the distribution channel stage, HP had to rely on the sales orders from the resellers to make product forecasts, plan capacity, control inventory, and schedule production. Big variations in demand were a major problem for HP's management. The common symptoms of such variation could be excessive inventory, poor product forecasts, insufficient or excessive capacities, poor customer service due to unavailable products or long backlogs, uncertain production planning (i.e. excessive revisions), and high costs for corrections, such as for expensive shipments and overtime. HP's product division was a victim of order swings that were exaggerated by the resellers relative to their sales; it, in turn, created additional exaggerations of order swings to suppliers.

Other industries are also in a similar position. Computer factories and manufacturers' distribution centers. the distributors' warehouse, and store warehouses along the distribution channel have the inventory stockpiles because of the bullwhip effect. And in the pharmaceutical industry, there are duplicated inventories in a supply chain of manufacturers such as Eli Lilly or Bristol-Myers Squibb, distributors such as McKesson. and retailers such as Longs Drug Stores. Information distortion can cause the total inventory in this supply chain to exceed 100 days of supply. With inventories of raw materials. such as integrated circuits and printed circuits boards in the computer industry and antibodies and vial manufacturing in the pharmaceutical industry, the total chain may contain more than one year's supply.

To solve the problem of distorted information which leads to demand variability, companies need to first understand what creates the bullwhip effect so they can counteract it. In industries where the entire SC can consist of numerous layers, this means that the majority of information that managers use to make decisions is only navailable to a few participants and concealed from those further up and down the SC [2]. Without a clear view of end-user demand, companies must rely on only that information to which they have access. Unfortunately, this information is usually distorted by multiple layers of forecasts and transactions. This lack of coordination can cause multiple problems, including increases in manufacturing costs, inventory costs, replenishment lead times, transportation costs, and labor costs associated with shipping, and damages to the level of product availability. Innovative companies in different industries have found that they can control the bullwhip effect and improve their supply chain performance by coordinating information and planning along the supply chain.

2.3 TECHNIQUES TO REDUCE THE BULLWHIP EFFECT

In supply chain the effect of bullwhip has a great impact; numerous researchers from different background have studied it. Several authors have investigated techniques for reducing the bullwhip effect through redesigning the supply chain. improving information flows, reducing time delays and improving order policies.

All the studies can be divided in to some major areas like,

i. Classical Management techniques.

ii. Control Theory.

iii. Computer Intelligence.

2.3.1 Classical Management Techniques

Classical management Techniques are widely employed to reduce the bullwhip effect in supply chain. It includes information sharing, forecasting, vendor managed inventory, scheduling problems. inventory problems. Various researchers have worked to identify the existence of bullwhip as well and to quantity that.

2.3.1.1 Information sharing

Many industries have embarked on reengineering efforts to improve the efficiency of their supply chains. The goal of these programs is to better match supply with demand so as to reduce the costs of inventory and stock outs and thus to eliminate the bullwhip effect. One key initiative that is commonly mentioned is information sharing between partners in a supply chain [8]. Sharing sales information has been viewed as a major strategy to counter the "bullwhip effect" [1, 2]. The bullwhip effect is essentially the phenomenon of demand variability amplification along a supply chain. from the retailers, distributors, manufacturer, and the manufacturers' suppliers, and so on. By letting the supplier have visibility of point-of-sales data, the harmful effect of demand distortion can be ameliorated. The most celebrated implementation of demand information sharing is Wal-Mart's Retail Link program, which provides on-line summary of point-of sales data to suppliers such as Johnson and Johnson, and Lever Brothers [9].

There has been more interest in quantifying the value of information sharing between manufacturers and retailers. Researchers like Cachon and Fisher [10] show analytically how the manufacturer can benefit from using information about the retailer's inventory levels when the retailers use a batch ordering policy. Next. Gavirneni et al. [11] consider the case in which the manufacturer has limited capacity. In addition, they consider two cases of information sharing between the manufacturer and the retailer. In the first case, the manufacturer obtains information from the retailer about the parameters of the underlying demand distribution and the value of the (s, S) ordering policy adopted by the retailer. In the second case, the manufacturer obtains additional information from the retailer about the period-to period inventory level. They compare the cost between the first and the second case so as to evaluate the benefit of obtaining additional information about the retailer's inventory level. By considering various types of demand distributions in their numerical experiments, they examine the conditions under which gaining information about the retailer's inventory level is beneficial.

Thus. the benefit of information sharing lies in the manufacturer's capability to react to the retailer's needs via the knowledge of the retailer's inventory levels to help reduce uncertainties in the demand process faced by the manufacturer.

2.3.1.2 Forecasting

The use of demand forecasting is one of the main five causes of the bullwhip effect. Appropriate forecasting has always been an important factor in order to reduce bullwhip effect. Many researchers have studied different factors of forecasting methods to mitigate bullwhip. Chen et. al [12] show how forecasting is used to reduce bullwhip effect as they quantify the bullwhip effect in a two stage supply chain consisting of a single retailer and a single manufacturer. The retailer does not know the true distribution of demand, and there for uses a simple moving average forecast to estimate the mean and the variance of demand. Hanssens [13] shows how a forecasting technique is linked to bullwhip effect; he quantifies the effect and shows how the use of accurate retail information can improve the accuracy of order forecasting. Chen et al. [12] study the impact of exponential smoothing and moving average forecasting algorithms on BWE and conclude that simple exponential smoothing leads to larger variability amplification than moving average. They confirm their analytical results using simulation experiments. Chatfield [14] also used forecasting to study bullwhip.

2.3.1.3 Vendor Managed Inventory (VMI)

Vendor-managed inventory (VMI) is one of the most widely discussed partnering initiatives for improving multi-firm supply chain efficiency and to reduce bullwhip effect. Also known as continuous replenishment or supplier-managed inventory, it was popularized in the late 1980's by Wal-Mart and Procter & Gamble. VMI became one of the key programs in the grocery industry's "quick response." Successful VMI initiatives have been trumpeted by other companies in the United States, including Campbell Soup and Johnson & Johnson and by European firms such as Barilla, the pasta manufacture [15].

Many researchers interested in bullwhip effect have studied VMI to find out its effect on the reduction of bullwhip. Disney and Towill [16] compares the bullwhip properties of a vendor managed inventory (VMI) supply chain with those of a traditional supply chain. The emphasis of their investigation is the comparative impact the two structures have on the "bullwhip effect" generated. In their research particular attention is paid to the manufacturer's production ordering activities as demonstrated using a simulation model based on difference equations. The study documents and considers each of the four important sources of the bullwhip effect in turn. The analysis shows that with VMI implementation two sources of the bullwhip effect may be completely eliminated, i.e. rationing and gaming or the Houlihan effect, and the order batching effect or the Burbidge effect. VMI is also significantly better at responding to rogue changes in demand due to the promotion effect or to price induced variations. However, the effect of VMI on demand signal processing induced bullwhip or the Forrester effect is less clear cut. This research concludes that on balance VMI offers a significant opportunity to reduce the bullwhip effect in real-world supply chains.

Some other researcher said that MI has been widely touted in recent years. Yet the successful implementation depends heavily on sound business processes and interpersonal relationships. Effective teamwork is required, with strong participation by both manufactures and retailers in order to make VMI successful [15]. Moreover, trust between supply chain partners is critical. Both must experience (and recognize) clear benefits, or the relationship is doomed. Waller et al [15] says organization incentives and metrics must be aligned with VMI goals. For example, sales bonuses are often tied to short-term sales goals that are inconsistent with VMI. Clearly VMI relationships will fail without necessary relationships, metrics, and organizational structure.

2.3.1.4 Scheduling problems

In many supply chains, the variability of orders may considerably increase relative to the variability of the buyers' demand. This variability increase is largely an effect of the ordering policy. This phenomenon, which has become known as the bullwhip effect, makes supply chain planning difficult. Many researchers have taken interest in this sector and investigated scheduling problems.

Researchers like Kelle and Milne [17] consider the following three basic elements of a supply chain: the purchase orders of the individual retailers, the aggregate orders of the retailers, and the supplier's ordering/production policy. A complex multi-echelon distribution system can also be analyzed by combining these elements. They investigate how the (s, S) policy parameters, the demand parameters, and the cost coefficients influence the variability of the orders. They also show how demand correlation can decrease the variability of aggregate orders, and how autocorrelation in buyer's orders can smooth the supplier's ordering policy. However, these variability reductions are usually not considerable. Small frequent orders can reduce the effect of high variability and the resulting uncertainty.

Researcher Cachon [18] studies supply chain demand variability in a model with one supplier and N retailers that face stochastic demand. Retailers implement scheduled ordering policies. Orders occur at fixed intervals and are equal to some multiple of a fixed batch size. A method is presented that exactly evaluates costs. This research shows that the supplier's demand variance will (generally) decline as the retailers' order interval is lengthened or as their batch size is increased. Lower supplier demand variance can certainly lead to lower inventory at the supplier and reduce bullwhip effect.

2.3.1.5 Inventory Problems

Inventory problem is also investigated by many researchers to reduce bullwhip effect. The bullwhip effect is an important supply chain phenomenon where small variations in end item demand create oscillations that amplify throughout the chain. The variance of the orders at the end user placed on suppliers or on manufacturer increases with the orders flow upstream in the logistics chain. This creates harmful consequences in inventory levels and all kind of inventory costs that may affect added value of activities along the logistics chain and finally affect Net Present Value of all activities in the chain [19].

Nowadays, effective and competitive company operation can be achieved through incorporating the concept of supply chain operation into company management. Inventory control, as a critical part of the supply chain management, becomes the second most frequent application area for simulation technique in logistics (after manufacturing) [20]. The dynamics of supply chain operation is characterized by the bullwhip effect that reflects an increase in demand variability while moving upwards the supply chain. The bullwhip effect can lead to holding an excessive inventory, insufficient capacities and high transportation costs. It is important to investigate the magnitude of this effect by quantifying it. This researcher proposes an analytical model for the analysis and numerical evaluation of the bullwhip effect in supply chains.

2.3.1.6 Others

Researcher Samuel and Mahanty [21] have identified problems with shortage gaming, which is another major cause of the bullwhip effect. Logistics problems have also been identified with and many researchers like Sheu [22] have taken interest in this sector.

2.3.2 CONTROL THEORY

Control theory is another popular approach to examining and reducing the bullwhip effect. Researchers applied z-transforms to the problem the bullwhip effect, even used transfer function analysis to reduce the bullwhip effect. Researcher McCullen and Towill [23] investigate and present an approach through agile manufacturing to reduce bullwhip. These researchers present four material flow principles which can be employed to reduce the bullwhip effect. They also present a case study from the precision mechanical engineering section to illustrate the effect of rapid response manufacturing and supply chain integration. Analysis of six years of time-series data indicates bullwhip reduction of up to 58 per cent. These results serve to validate the four material flow principles of selecting appropriate control systems, time-compression, information transparency, and echelon elimination. They also raise interesting questions concerning the relationship between manufacturing agility and lean supply. Researcher Dejonckheere et al. [24] also used control theory to reduce bullwhip effect.

2.3.3 COMPUTER INTELLIGENCE

Most of the researchers' main interest is on information and forecasting methods in case of reducing bullwhip. These techniques are promising if members of an SC share information. However, the majority of companies are still reluctant to do this. Control theory presents a theoretical approach to reduce the bullwhip effect but is inappropriate for implementing in complex Supply Chains. Vendor Managed Inventory (VMI) is an excellent method for reducing the bullwhip effect and has been employed by many international companies such as Procter and Gamble, and Walmart [1, 2]. The principal problem associated with this method is the sharing of information between retailer and factory. Computational intelligence (CI) techniques present an alternative approach to classical management techniques. CI techniques provide more computationally powerful algorithms, which provide the capability to exhaustively search complex situations. Classical management techniques may find the local optimum instead of the global optimum. CI approaches are more robust and have better generalizations, i.e. the technique employed can be easily modified to optimize a similar problem.

There are three main techniques that may be used in a CI approach, as described

- Fuzzy logic.
- Artificial Neural Networks.
- Genetic Algorithm.

2.3.3.1 Fuzzy Logic

Fuzzy logic (FL) is modeled on the reasoning part of the human brain. Its main advantage is that it can deal with vague and imprecise data. Humans do not need precise numerical data to make decisions, whereas computers do, and FL is modeled on a similar principle. The outputs of the systems are not a precise mathematical answer but are still a 'good enough' answer.

Different researchers used Fuzzy Logic to reduce bullwhip effect. Researcher Carlson and Fuller [25] is one of them. They consider a series of companies in a supply chain, each of which orders from its immediate upstream collaborators. Usually, the retailer's order does not coincide with the actual retail sales. They show that if the members of the supply chain share information with intelligent support technology, and agree on better and better fuzzy estimates (as time advances) on future sales for the upcoming period, then the bullwhip effect can be significantly reduced.

2.3.3.2 Artificial Neural Networks (ANN)

An Artificial Neural Network (ANN) is an information processing paradigm inspired by the way biological nervous systems such as the brain, process information and learns from experience. In other words, ANNs focus on replicating the learning process performed by the brain. Humans have the ability to learn new information, store it, and return to it when needed. Humans also have the ability to use this information when faced with a problem similar to that they have learned from in the past.

2.3.3.3 Genetic Algorithms

Genetic Algorithms (GAs) are a class of algorithm, which are powerful optimization tools that imitate the natural process of evolution and Darwin's principal of 'Survival of the Fittest'. In the process of evolution, weaker individuals tend to die off, and stronger ones tend to live longer and reproduce. GAs optimize in a similar manner, by simulating the Darwinian evolutionary process and naturally occurring genetic operators on chromosomes. GAs are used to solve extremely complex search and optimization problems which prove difficult using analytical or simple enumeration methods. GAs do not carry out examinations sequentially but search in parallel mode using a multi individual population, where each individual is being examined at the same time. GAs provide an efficient and robust method of obtaining global optimization in difficult problems. GAs do not require derivative information found in analytical optimization. A GA works well with numerically generated data, experimental data, or analytical functions, and has the ability to jump out of local minimum, i.e has the ability to find the global optimum.

Genetic algorithm has been used in many branches of supply chain. Researchers have always been interested to use new techniques to solve the problems of supply chain.

Researcher Kimbrough et al. [3] used genetic algorithm to solve the bullwhip effect found in MIT beer game. Genetic algorithms are also being used for planning of supply chain. Researcher Merkuryeva et al. [26] used multi objective simulation based genetic algorithm (MOSGA) for multi echelon supply chain cyclic planning and optimization. The problem involves a search in high dimensional space with different ranges for decision variable scales, multiple objectives and problem specified constraints. Lam et al. [27] propose genetic algorithm approach to develop a collaborative supply chain network, i.e. a supply chain network with genetic algorithm embedded so as to increase the efficiency and effectiveness of a supply chain network. They show that GA approach is capable of shortening the processing time and reducing operating time in the network. O'Donnell et al. [28] use genetic algorithm to reduce negative effect of sales promotion in supply chain. They show how GA can be used to assist supply managers in predicting reorder quantities along the supply chain as well as can reduce bullwhip effect. Researcher Disney et al. [29] describes a procedure for optimizing the performance of an industrially designed inventory control system using genetic algorithm. Zhou et al. [30] used genetic algorithm for balancing the allocation of customers to multiple distribution centers in the supply chain network. This researcher model goes beyond traditional mathematical programming by incorporating the genetic algorithm which is effective in dealing with complex problems.

CHAPTER 3
THEORETICAL BACKGROUND

3.1 INTRODUCTION

Supply chain management has generated much interest in recent years for a number of reasons. One of the most common dynamics in supply chains is a phenomenon that has been dubbed "the bullwhip effect." In this chapter the details about supply chain and bullwhip. the effect of bullwhip in supply chain has been discussed. The inventory policy used in the solution approach has also been discussed in this chapter. Later portion of the chapter deals with the details of genetic algorithm.

3.2 SUPPLY CHAIN MANAGEMENT

Supply chain management (SCM) is the term used to describe the management of the flow of materials, information, and funds across the entire supply chain, from suppliers to component producers to final assemblers to distribution (warehouses and retailers), and ultimately to the consumer. In fact, it often includes after-sales service and returns or recycling [31].

A supply chain is an integrated process which includes all activities associated with the flow and transformation of goods from raw material stage through to the end user. It also involves the integration of transformation of information which flows up and down the supply chain [32].

The supply chain activities begin with a customer order and end when a satisfied customer has paid for the purchase. Supply chain is a set of approaches utilized to efficiently integrate suppliers, manufactures, warehouses, and stores so that merchandise is produced and distributed at the right quantities, to the right locations and at the right time in order to minimize system wide costs while satisfying service level requirements [33].

3.2.1 Modern Supply Chains

Supply chains are networks of firms who pool their capabilities and resources in order to deliver value to the end consumer. Firms are no longer able to own or control complete supply chains. Information technology and modern logistics capabilities have created a global market where companies can take advantage of the opportunity to source internationally. Companies have thus specialized and "partnered" globally with other companies. These companies have then to increasingly focus on logistics and supply chain coordination. Such coordination is now an essential business process. Modern supply chain management starts with the premise that supply chain members are primarily concerned with optimizing their own objectives and this self-serving focus often results in poor performance. Another way of saying this is that a sequence of local optimum policies does not bring about a globally optimum solution. Munson et al. [34] summarize it as follows "When each member of a group tries to maximize his or her own benefit without regard to the impact on other members of the group, the overall effectiveness may suffer. Such inefficiencies often creep in when rational members of supply chains optimize individually instead of coordinating their efforts."

A well known example of such inefficiency is the bullwhip effect. This effect refers to the tendency of replenishment orders to increase in variability as one moves up the supply chain from retailer to manufacturer. A disintegrated material flow, combined with distorted demand information and a lack of replenishment rule alignment inevitably results in poor supply chain dynamics.

3.3 BULLWHIP EFFECT

The "bullwhip effect" is short-hand term for a dynamical phenomenon in supply chains. It refers to the tendency of the variability of order rates to increase as they pass through the echelons of a supply chain toward producers and raw material suppliers [35]. What happens is that small changes in product demand by the consumer at the front of the supply chain translate into wider and wider swings in demand experienced by companies' further back in the supply chain. So, bullwhip in short is the amplification of order variability along the supply chain [36]

Now, if a supply chain is consists of four members (retailer, distributor, manufacture and supplier), then figure 3.1 shows the pronounced variability in the retailers order to the distributor. Orders to the manufacturer and to the manufactures' supplier spike even more where consumer sales do not seem to vary much.

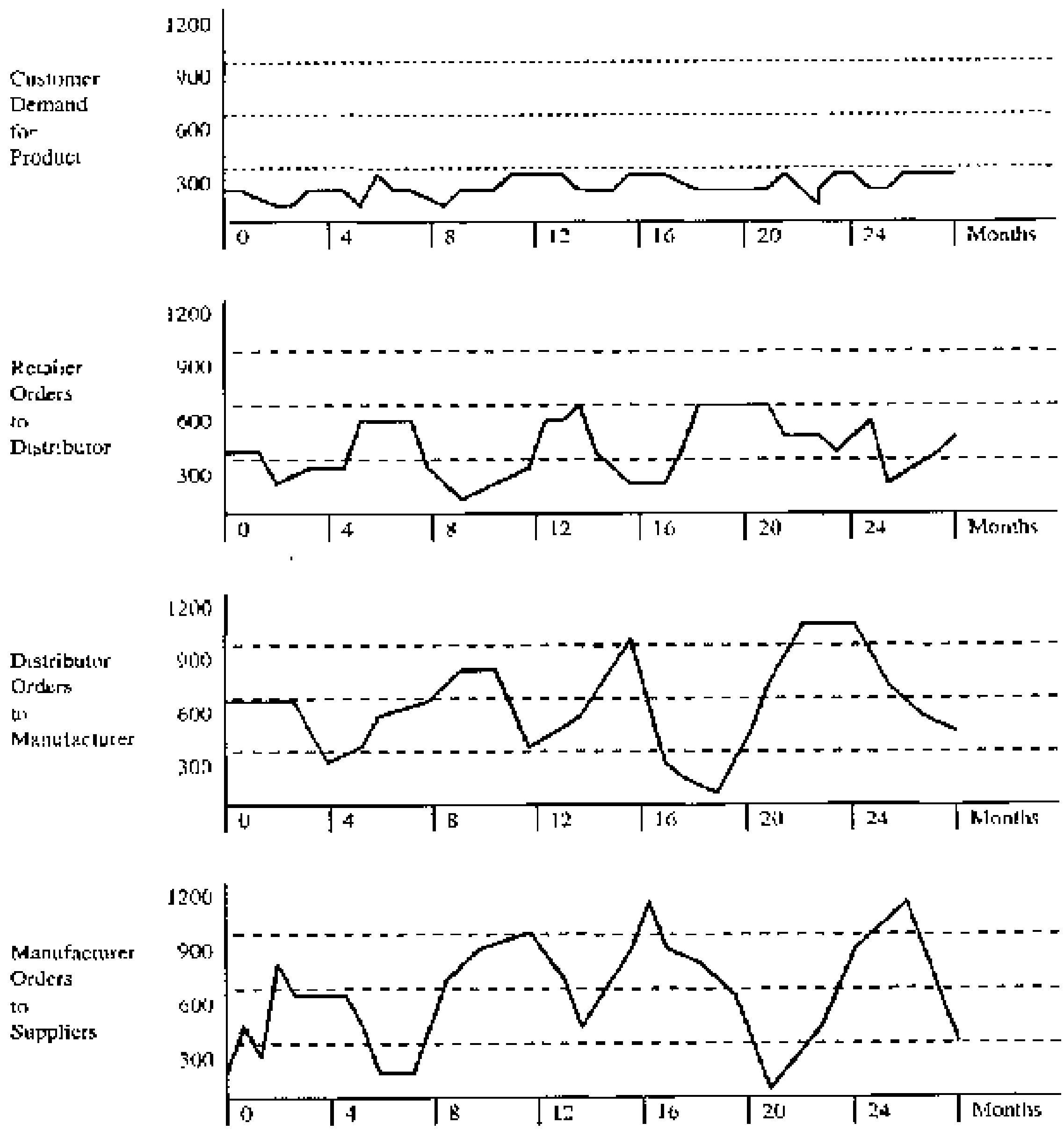

Figure 3.1: Increasing variability of orders up the supply chain [37]

3.3.1 Causes of Bullwhip Effect

Bullwhip effect is often created for mainly behavioral and operational causes. Now details about these causes are described below,

i. Behavioral causes.
ii. Operational causes.

3.3.1.1 Behavioral Causes

The behavioral causes are rather straightforward. Supply chain managers may not always be completely rational. Managers over-react (or under-react) to demand changes. Often people are over optimistic and confuse forecasts with targets. Decision makers sometime over-react to customer complaints and anecdotes of negative customer reactions. Moreover, there are cognitive limitations as supply chain networks are often very complicated, operating in a highly uncertain environment with limited access to data.

Croson and Donohue [38] and Sterman [39] found that decision makers consistently under-weight the supply chain. This means that they do not have a clear idea of what is available in the pipeline. This induces some form of decision bias. This clearly indicates that behavioral causes have a great impact on bull whip effect with or without the operational causes [40].

3.3.1.2 Operational Causes

Lee et al. [1, 2] identify five major operational causes of bullwhip. These factors interact with each other in different combinations in different supply chains but the net effect is that they generate the wild demand swings that make it so hard to run an efficient supply chain. These factors must be understood and addressed in order to coordinate the actions of any supply chain. They are,

- *Demand signal processing*

Demand signal processing as the practice of decision makers adjusting the parameters of the inventory replenishment rule. Target stock levels, safety stocks, and demand forecasts are updated in face of new information or deviations from targets [37]. It is important to realize that most players in supply chains do not respond directly to the market but respond to replenishment demand from downstream echelons. This is why local optimization often results in global disharmony.

- *Lead time*

A second major cause of the bullwhip problem is the lead-time. The lead-time is a key parameter for calculating safety stock, reorder points, and order-up-to levels. The increase in variability is magnified with increasing lead-time [1, 2].

- *Order batching*

Order batching occurs because companies place orders periodically for amounts of product that will minimize their order processing and transportation costs [37]. Because of order batching, these orders vary from the level of actual demand and this variance is magnified as it moves up the supply chain.

- *Price fluctuations*

The third major cause of bullwhip as highlighted by Lee et al [1, 2] has to do with price fluctuations. Retailers often offer price discounts, quantity discounts, coupons or in-store promotions. This results in forward buying where retailers (as well as consumers) buy in advance and in quantities that do not reflect their immediate needs.

- *Product rationing and shortage gaming*

A further cause of bullwhip is connected with rationing and shortage gaming. Inflated orders placed by supply chain members during shortage periods tend to magnify the bullwhip effect. Such orders are common when retailers and distributors suspect that a product will be in short supply. Exaggerated customers orders make it hard for manufacturers to forecast the real demand level.

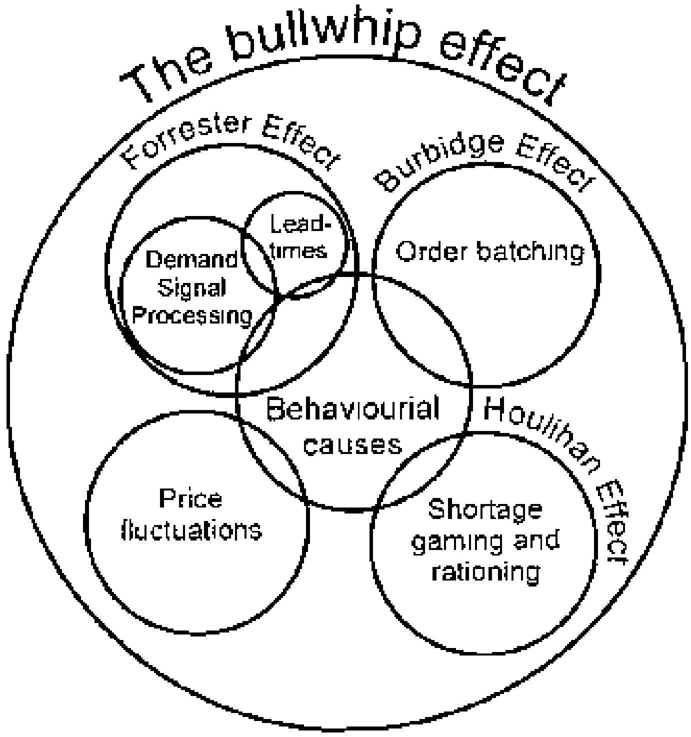

Figure 3.2: The causes of Bullwhip Effect [35]

3.3.2 Problems caused by bullwhip

Bullwhip effect is not harmful by itself, but because of its consequences. As unnecessary demand variability complicates the supply chain planning and execution processes, following undesirable effects increase in their severity as they negatively impact operating performance [41].

- *Excessive inventory investment:* Since the bullwhip effect makes the demand more unpredictable, all companies need to safeguard themselves against the variations to avoid stock out.

- *Poor customer service levels:* Despite the excessive inventory levels mentioned in the first consequences, demand unpredictability may cause stock out which cause poor customer service.

- *Lost revenue:* In addition to poor customer service stock out may cause lost revenue.

- *Schedule variability increases:* Since demand variability increase, schedule variability also increases.

- *Capacity is overloaded and/or under-loaded:* Bullwhip also causes overloading or under loading of capacity [42].

- *Cycle times lengthen:* Excess demand sometime increases the cycle time.

- *Overall costs increase:* To meet up the demand variability along with the above mentioned consequences the overall cost increases.

3.3.3 The link between bullwhip effect and supply chain costs

Bullwhip creates unstable production schedules. These unstable production schedules are the cause of a range of unnecessary costs in supply chains [35]. Companies have to invest in extra capacity to meet the highly variable demand. This capacity is then under-utilized when demand drops. Unit labor costs rise in periods of low demand, overtime, agency, and sub-contract costs rise in periods of high demand. The highly variable demand increases the requirements for safety stock in the supply chain. Additionally, companies may decide to produce to stock in periods of low demand to increase productivity. If this is not managed properly this will lead to excessive obsolescence. Highly variable demand also increases lead-times. These inflated lead-times lead to increased stocks and bullwhip effects. Thus the bullwhip effect can be quite exasperating for companies; they invest in extra capacity, extra inventory, work over-time one week and stand idle the next, while at the retail store the shelves of popular products are empty, and the shelves with products that are not selling are full. A cause and effect diagram in figure 3.3 highlights the interaction between demand variance and cost generation.

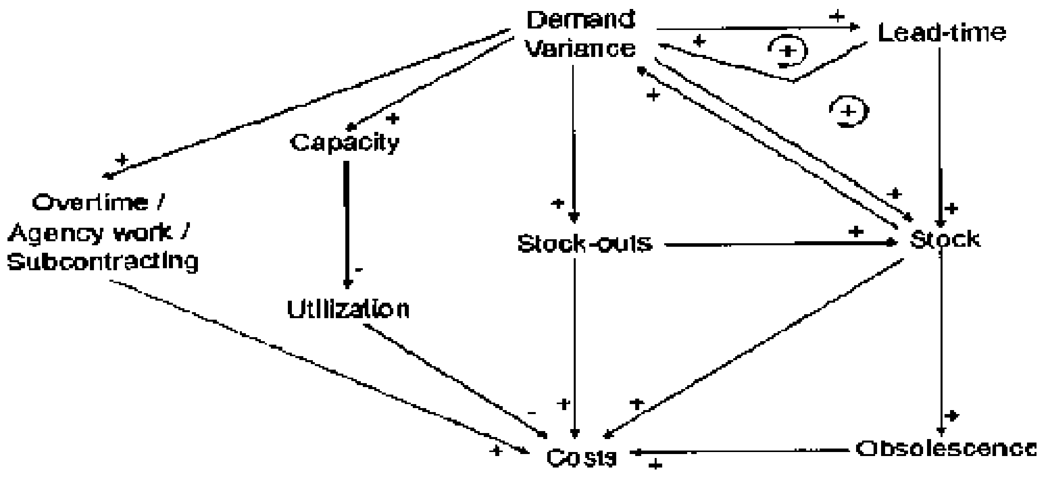

Figure 3.3: How bullwhip effect causes cost in a supply chain [3]

3.4 INVENTORY POLICY

The control and maintenance of inventory is a problem common to all organizations in any sector of the economy. Bullwhip effect results in increased safety stock, that's why inventory policy has a great influence on bullwhip effect [43]. In order to reduce bullwhip effect inventory policy must be such that which reduces extra amount of inventory. There are many different types of inventory policy. In this research Fixed Order Interval Policy is used and the details about is written below.

3.4.1 Fixed Order Interval Inventory Policy

In fixed order interval system, there is fixed order period and a varying order size. At predetermined intervals, the inventory is reviewed and an order is placed [44]. The characteristics of this model are,

- Orders are placed at fixed time intervals.
- Suppliers might encourage fixed intervals
- May require only periodic checks of inventory levels
- Easy, inexpensive to operate

3.5 GENETIC ALGORITHM

Charles Darwin stated the theory of natural evolution in the origin of species. Over several generations, biological organisms evolve based on the principle of natural selection "survival of the fittest" to reach certain remarkable tasks. The perfect shapes of the albatross wring the efficiency and the similarity between sharks and dolphins and so on. are best examples of achievement of random evolution over intelligence. Thus. it works so well in nature, as a result it should be interesting to simulate natural evolution and to develop a method, which solves concrete. and search optimization problems. In nature, an individual in population competes with each other for virtual resources like food, shelter and so on. Also in the same species, individuals compete to attract mates for reproduction. Due to this selection, poorly performing individuals have less chance to survive, and the most adapted or "fit" individuals produce a relatively large number of offspring's. It can also be noted that during reproduction, a recombination of the good characteristics of each ancestor can produce "best fit" offspring whose fitness is greater than that of a parent. After a few generations, species evolve spontaneously to become more and more adapted to their environment [45]. In 1975, Holland developed this idea in his book "Adaptation in natural and artificial systems". He described how to apply the principles of natural evolution to optimization problems and built the first Genetic Algorithms. Holland's theory has been further developed and now Genetic Algorithms (GAs) stand up as a powerful tool for solving search and optimization problems. Genetic algorithms are based on the principle of genetics and evolution.

3.5.1 Biological Background

The science that deals with the mechanisms responsible for similarities and differences in a species is called Genetics, the science which helps us to differentiate between heredity and variations. The concepts of Genetic Algorithms are directly derived from natural evolution or genetics. The main terminologies involved in the biological background of species are as follows:

3.5.1.1 The Cell

Every animal/human cell is a complex of many "small" factories that work together. The center of all this is the cell nucleus. The genetic information is contained in the cell nucleus.

3.5.1.2 Chromosomes

All the genetic information gets stored in the chromosomes. The chromosomes are divided into several parts called genes. Genes code the properties of species i.e., the characteristics of an individual. The possibilities of the genes for one property are called allele and a gene can take different alleles. For example, there is a gene for eye color, and all the different possible alleles are black, brown, blue and green (since no one has red or violet eyes). The set of all possible alleles present in a particular population forms a gene pool. This gene pool can determine all the different possible variations for the future generations. The size of the gene pool helps in determining the diversity of the individuals in the population. The set of all the genes of a specific species is called genome. Each and every gene has a unique position on the genome called locus. In fact, most living organisms store their genome on several chromosomes, but in the Genetic Algorithms (GAs), all the genes are usually stored on the same chromosomes [46]. Thus chromosomes and genomes are synonyms with one other in GAs.

3.5.1.3 Genetics

For a particular individual, the entire combination of genes is called genotype. The phenotype describes the physical aspect of decoding a genotype to produce the phenotype. One interesting point of evolution is that selection is always done on the phenotype whereas the reproduction recombines genotype. Thus morphogenesis plays a key role between selection and reproduction.

3.5.1.4 Reproduction

Reproduction of species via genetic information is carried out by. Mitosis and Meiosis. In Mitosis the same genetic information is copied to new offspring. There is no exchange of information. This is a normal way of growing of multi cell structures, like organs. When meiotic division takes place genetic information is shared between the parents in order to create new offspring.

3.5.1.5 Selection

The origin of species is based on "Preservation of favorable variations and rejection of unfavorable variations". The variation refers to the differences shown by the individual of a species and also by offspring's of the same parents. There are more individuals born than can survive, so there is a continuous struggle for life. Individuals with an advantage have a greater chance for survive i.e.. the survival of the fittest. As a result, natural selection plays a major role in this survival process.

Thus the various biological terminologies to be used in genetic algorithms were discussed in this section.

3.5.2 Terminologies and Operators of GA

3.5.2.1 Key Elements

The two distinct elements in the GA are individuals and populations. An individual is a single solution while the population is the set of individuals currently involved in the search process.

i Individual

An individual is a single solution.

ii Population

A population is a collection of individuals. A population consists of a number of individual being tested, the phenotype parameters defining the individuals

3.5.2.2 Genes

Genes are the basic "instructions" for building a Generic Algorithms. A chromosome is a sequence of genes. Genes may describe a possible solution to a problem, without actually being the solution. A gene is a bit string of arbitrary lengths.

3.5.2.3 Fitness

The fitness of an individual in a genetic algorithm is the value of an objective function for its phenotype. For calculating fitness, the chromosome has to be first decoded and the objective function has to be evaluated. The fitness not only indicates how good the solution is, but also corresponds to how close the chromosome is to the optimal one.

3.5.2.4 Encoding

Encoding is a process of representing individual genes. The process can be performed using bits, numbers, trees, arrays, lists or any other objects. The encoding depends mainly on solving the problem. For example, one can encode directly real or integer numbers.

i. Binary Encoding

The most common way of encoding is a binary string, which would be represented as

Chromosome 1	1 1 1 1 1 0 0 1 1 0 1 0
Chromosome 2	0 1 1 1 0 0 0 0 1 1 0 0

Each chromosome encodes a binary (bit) string. Each bit in the string can represent some characteristics of the solution. Every bit string therefore is a solution but not necessarily the best solution. Binary encoding gives many possible chromosomes with a smaller number of alleles. On the other hand this encoding is not natural for many problems and sometimes corrections must be made after genetic operation is completed [47]. Binary coded strings with 1s and 0s are mostly used. The length of the string depends on the accuracy.

ii Octal Encoding

This encoding uses string made up of octal numbers (0–7).

Chromosome 1	03467216
Chromosome 2	15723314

iii. Hexadecimal Encoding

This encoding uses string made up of hexadecimal numbers (0–9, A–F).

Chromosome 1	9CE7
Chromosome 2	3DBA

iv. Permutation Encoding (Real Number Coding)

Every chromosome is a string of numbers, which represents the number in sequence. In permutation encoding, every chromosome is a string of integer/real values, which represents number in a sequence.

Chromosome A	1	5	3	2	6	7	9	8	3
Chromosome B	8	5	6	3	7	5	6	1	8

Permutation encoding is only useful for ordering problems like traveling sales man etc.

v. Value Encoding

Every chromosome is a string of values and the values can be anything connected to the problem. This encoding produces best results for some special problems. Direct value encoding can be used in problems, where some complicated values, such as real numbers, are used.

Use of binary encoding for this type of problems would be very difficult [47]. In value encoding, every chromosome is a string of some values. Values can be anything connected to problem, form numbers, real numbers or chars to some complicated objects.

Chromosome A	1.0	5	3	2	6	7
Chromosome B	A	B	D	E	I	F
Chromosome C	back	right	Back	left	left	Right

vi. Tree Encoding

This encoding is mainly used for evolving program expressions for genetic programming.

Every chromosome is a tree of some objects such as functions and commands of programming language.

3.5.2.5 Breeding

The breeding process is the heart of the genetic algorithm. It is in this process, the search process creates new and hopefully fitter individuals [47].

The breeding cycle consists of four steps.

a. Selecting parents.

b. Crossing the parents to create new individuals (offspring or children).

c. Mutation of the offsprings.

d. Replacing old individuals in the population with the new ones.

3.5.2.5.1 Selection

Selection is the process of choosing two parents from the population for crossing. After deciding on an encoding, the next step is to decide how to perform selection. The purpose of selection is to emphasize fitter individuals in the population in hopes that their off springs have higher fitness. Chromosomes are selected from the initial population to be parents for reproduction.

Selection is a method that randomly picks chromosomes out of the population according to their evaluation function. The higher the fitness function, the more chance an individual has to be selected. The various selection methods are discussed as follows:

i. RouletteWheel Selection

Roulette selection is one of the traditional GA selection techniques. The commonly used reproduction operator is the proportionate reproductive operator where a string is selected from the mating pool with a probability proportional to the fitness. The principle of roulette selection is a linear search through a roulette wheel with the slots in the wheel weighted in proportion to the individual's fitness values. A target value is set, which is a random proportion of the sum of the fit nesses in the population [47]. The population is stepped through until the target value is reached. This is a moderately strong selection technique.

ii. Random Selection

This technique randomly selects a parent from the population. In terms of disruption of genetic codes, random selection is a little more disruptive, on average, than roulette wheel selection.

iii. Rank Selection

Rank Selection ranks the population and every chromosome receives fitness from the ranking. The worst has fitness 1 and the best has fitness N. It results in slow convergence but prevents too quick convergence. It also keeps up selection pressure when the fitness variance is low.

iv. Tournament Selection

The tournament selection strategy provides selective pressure by holding a tournament competition among Nu individuals. The best individual from the tournament is the one with the highest fitness, which is the winner of Nu. Tournament competitions and the winner are then inserted into the mating pool. The tournament competition is repeated until the mating pool for generating new offspring is filled. The mating pool comprising of the tournament winner has higher average population fitness. The fitness difference provides the selection pressure, which drives GA to improve the fitness of the succeeding genes.

3.5.2.5.2 Crossover (Recombination)

Crossover is the process of taking two parent solutions and producing from them a child. After the selection (reproduction) process, the population is enriched with better individuals. Crossover operator is applied to the mating pool with the hope that it creates a better offspring.

Crossover is a recombination operator that proceeds in three steps,

i. The reproduction operator selects at random a pair of two individual strings for the mating.
ii. A cross site is selected at random along the string length.
iii. Finally, the position values are swapped between the two strings following the cross site.

i. Single Point Crossover

The traditional genetic algorithm uses single point crossover, where the two mating chromosomes are cut once at corresponding points and the sections after the cuts are exchanged.

Chromosome 1	1	1	1	1	1	0	0	1	1	0	1	0
Chromosome 2	0	1	1	1	0	0	0	0	1	1	0	0

Offspring 1	1	1	1	1	1	0	0	0	1	1	0	0
Offspring 2	0	1	1	1	0	0	0	1	1	0	1	0

ii. Two Point Crossover

In two-point crossover, two crossover points are chosen and the contents between these points are exchanged between two mated parents.

Chromosome 1	2	3	4	5	6	7	8	9	0	1	5	7
Chromosome 2	A	C	B	E	F	B	R	T	S	E	R	G

Offspring 1	2	3	4	5	6	B	R	T	S	E	5	7
Offspring 2	A	C	B	E	F	7	8	9	0	1	R	G

iii. Uniform Crossover

Uniform crossover is quite different from the N-point crossover. Each gene in the offspring is created by copying the corresponding gene from one or the other parent chosen according to a random generated binary crossover mask of the same length as the chromosomes. Where there is a 1 in the crossover mask, the gene is copied from the first parent, and where there is a 0 in the mask the gene is copied from the second parent. The number of effective crossing point is not fixed, but will average L/2 (where L is the chromosome length).

Chromosome 1	**1**	**0**	**1**	**1**	**0**	**0**	**1**	**1**
Chromosome 2	**0**	**0**	**0**	**1**	1	**0**	**1**	**0**
Mask	1	1	**0**	**1**	**0**	1	**1**	**0**
Offspring 1	**1**	**0**	**0**	**1**	1	**0**	**1**	**0**
Offspring 2	**0**	**0**	**1**	**1**	**0**	**0**	**1**	**1**

iv. Three Parent Crossover

In this crossover technique, three parents are randomly chosen. Each bit of the first parent is compared with the bit of the second parent. If both are the same, the bit is taken for the offspring otherwise; the bit from the third parent is taken for the offspring.

Chromosome 1	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**1**
Chromosome 2	**0**	**1**	**1**	**0**	1	**0**	**0**	**1**
Chromosome 3	**0**	1	1	**0**	1	1	**0**	**0**
Offspring 1	**0**	1	1	**0**	1	**0**	**0**	**1**

3.5.2.5.3 Mutation

After crossover, the strings are subjected to mutation. Mutation prevents the algorithm to be trapped in a local minimum. Mutation plays the role of recovering the lost genetic materials as well as for randomly disturbing genetic information If crossover is supposed to exploit the current solution to find better ones, mutation is supposed to help for the exploration of the whole search space. It introduces new genetic structures in the population by randomly modifying some of its building blocks. Mutation helps escape from local minima's trap and maintains diversity in the population. There are many different forms of mutation for the different kinds of representation. The important parameter in the mutation technique is the mutation probability (Pm). The mutation probability decides how often parts of chromosome will be mutated. If there is no mutation, offspring are generated immediately after crossover (or directly copied) without any change

3.5.2.5.4 Replacement

Replacement is the last stage of any breeding cycle. Basically, there are two kinds of methods for maintaining the population: generational updates and steady state updates. The basic generational update scheme consists in producing *N* children from a population of size *N* to form the population at the next time step (generation), and this new population of children completely replaces the parent selection. In a steady state update, new individuals are inserted in the population as soon as they are created, as opposed to the generational update where an entire new generation is produced at each time step.

3.5.2.6 Search Termination

In short, the various stopping condition are listed as follows:

• **Maximum generations:** The genetic algorithm stops when the specified number of generations has evolved.

• **Elapsed time:** The genetic process will end when a specified time has elapsed.

• **No change in fitness:** The genetic process will end if there is no change to the population's best fitness for a specified number of generations.

3.5.3 Outline of Genetic Algorithm

An algorithm is a series of steps for solving a problem. A genetic algorithm is a problem solving method that uses genetics as its model of problem solving. It's a search technique to find approximate solutions to optimization and search problems. The basic of genetic algorithm is as follows:

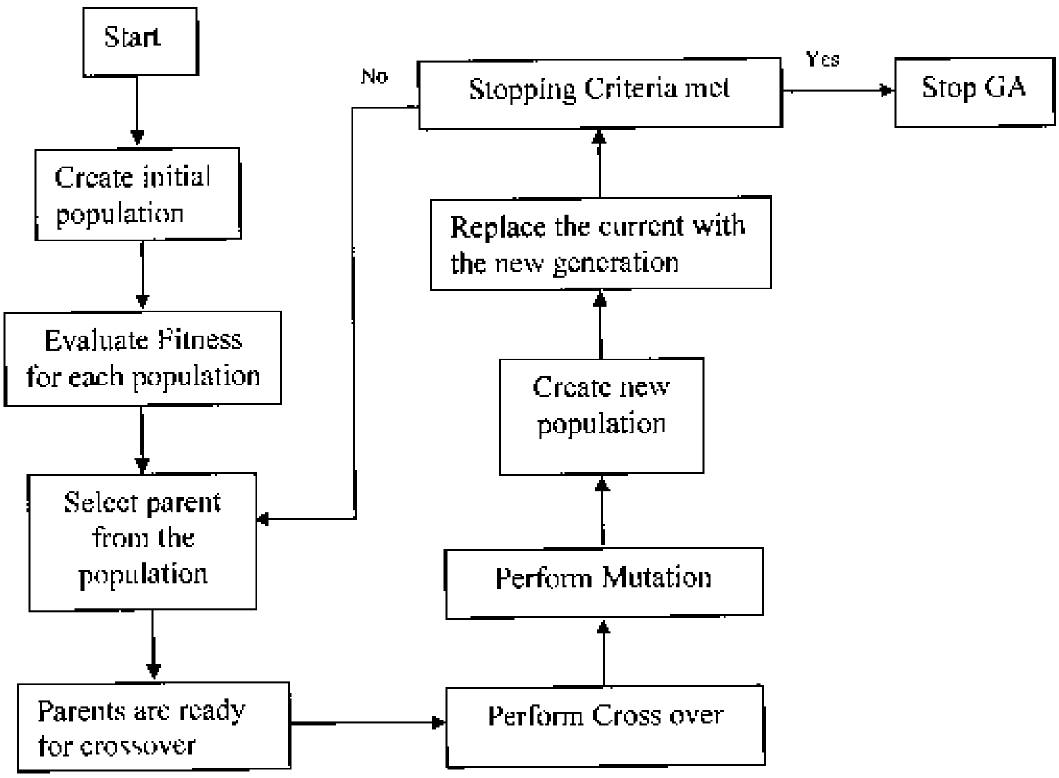

Figure 3.4: Outline of Genetic Algorithm

3.5.4 Advantages and Limitations of Genetic Algorithm

The advantages of genetic algorithm include,

- Solution space is wider.
- The fitness landscape is complex.
- Easy to discover global optimum.
- The problem has multi objective function.

- Easily modified for different problems.
- Handles noisy functions well.
- Handles large search spaces easily.
- Very robust to difficulties in the evaluation of the objective function.
- They are resistant to becoming trapped in local optima.
- They perform very well for large-scale optimization problems.
- Can be employed for a wide variety of optimization problems.

The limitations of genetic algorithm include,

- The problem of identifying fitness function.
- Premature convergence occurs.
- The problem of choosing the various parameters like the size of the population, mutation rate, cross over rate, the selection method and its strength.
- Cannot easily incorporate problem specific information.
- Not good at identifying local optima.
- No effective terminator.

CHAPTER 4
METHODOLOGY TO REDUCE BULLWHIP EFFECT

4.1 INTRODUCTION

Theoretically the Bullwhip effect does not occur if all orders exactly meet the demand of each period, otherwise results in greater safety stock which can lead to either inefficient production or excessive inventory as the producer needs to fulfill the demand of its predecessor in the supply chain. This also leads to a low utilization of the distribution channel. Despite of having safety stocks there is still the hazard of stock-outs which result in poor customer service. Furthermore. the bullwhip effect leads to a row of financial costs. It will increase the inventory cost, backorder cost, distribution cost etc. In order to reduce the bullwhip effect in supply chain a systematic approach is applied in this research.

4.2 SOLUTION APPRAOCH

To reduce the bullwhip effect of supply chain a step by step procedure is adopted. where at first the objective functions are set, then different criteria to meet those objective functions are set like inventory polices, different types of costs needed etc. and finally an algorithm is applied to get the best results. So, the Bullwhip effect reduction process is as follows,

i. Collecting demand data.
ii. Setting a objective functions
iii. Setting inventory polices and costs for different purposes.
iv. Apply Genetic Algorithm.

4.3 COLLECTING CUSTOMER DEMAND

The first step to reduce bull whip effect and to find the optimal ordering quantities for the supply chain is to collect the forecasted customer demand for a particular time period.

4.4 SETTING OBJECTIVE FUNTIONS

In order to reduce the bullwhip effect, the second step is to set the objective function. The main objective here is to reduce costs of supply chain for each member which will ultimately reduce the total supply chain cost. The logic works here if the total supply chain costs are lowered, then automatically bull whip will be reduced as to maintain a lower cost each member will order less and thus demand amplification will be reduced. In a supply chain different types of costs are associated. A member of supply chain usually has to pay maximum five different types of cost which are described details in below.

4.4.1 Inventory cost

Inventory cost [3] is for holding inventory which depends on inventory level.
The formula for inventory cost is,

$$INVC_i(t) = INV_i(t) \times H_i(t), \text{ if } INV_i(t) \geq 0$$

Here,

$INVC_i(t)$ = Inventory holding cost for member i at time t.

$INV_i(t)$ = Inventory level for member i at time t.

H_i = Inventory unit holding cost price for member i at time t.

4.4.2 Backorder cost

Back order cost [3] is a type which rises if any member's inventory is not enough to meet the demand from downstream members of the supply chain.

The formula for back order cost is,

$$BKC_i(t) = UFD_i(t) \times B_i(t),$$

Here,

$BKC_i(t)$=back order cost for member i at time t.

$UFD_i(t)$ = back orders for member i at time t.

$B_i(t)$ = backorder unit cost price for member i at time t.

4.4.3 Ordering cost

Third type of cost is ordering cost [48] for placing orders.

The formula for ordering cost is,

$$OC_i(t) = \begin{cases} R_i(t), & \text{if } O_{ij}(t) > 0, \\ 0, & \text{if } O_{ij}(t) = 0 \end{cases}$$

Here.

$OC_i(t)$ = ordering cost for member i at time t.

$R_i(t)$ = ordering cost at time t,

$O_{ij}(t)$ = order from member i for member j at time t.

4.4.4 Distribution cost

Forth cost is distribution cost, which consists of shipping cost, item cost, and cargo cost [49], arrives when a member of supply chain delivers items to the buyer and the buyer pays for it.

The formula for distribution cost is,

$$DC_i(t) = \{a_{ij}(t) + b_i(t)\} \times x_{ij}(t) + \frac{x_{ij}(t)}{Q_i} \times VC_{ij}(t)$$

Here,

$a_{ij}(t)$ = unit shipping cost from member i to member j at time t,

$b_i(t)$) = unit price of the item for member i during time t,

$x_{ij}(t)$ = number of units distributed from member i to member j at time t,

$VC_{ij}(t)$ = cost of per cargo shipping from member i to member j in time t,

Q_i = cargo capacity of the member i.

4.4.5 Production cost

Finally production costs [50] which is applied to only factory when is orders from production line.

The formula for production cost is,

$$PC_i(t) = D_{ij}(t) \times CU_i(t)$$

Here,

$PC_i(t)$ = production cost for factory.

$D_{ij}(t)$ = demand that member j receives from member i in time t.

$CU_i(t)$ = production unit cost price for member i at time t.

4.4.6 Objectives

Now, if a supply chain is consists of a retailer, a distributor, a warehouse and factory, then to minimize the total supply chain cost, costs for each member should be reduced. The below diagram shows a three stage supply chain model.

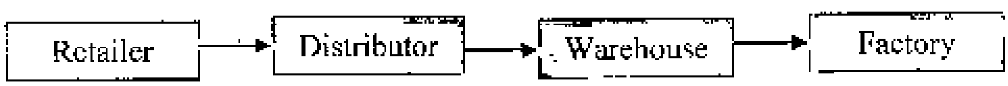

Figure 4.1: Flow diagram of a supply chain

So, the objectives are represented below:

i. Minimize the supply chain cost for retailer at time t ($C_1(t)$). A retailer's supply chain cost consists of Inventory cost, Backorder cost and Ordering cost.

Minimize,

$$C_1(t) = INVC_i(t) + BKC_i(t) + OC_i(t)$$

$$= INV_i(t) \times H_i(t) + UFD_i(t) \times B_i(t) + OC_i(t)$$

ii. Minimize the supply chain cost for distributor at time t ($C_2(t)$): A distributor's supply chain cost consists of Inventory cost, Backorder cost, Ordering cost and Distribution cost.

Minimize,

$$\mathbf{C_2(t)} = INVC_i(t) + BKC_i(t) + OC_i(t) + DC_i(t)$$

$$= INV_i(t) \text{ X } H_i(t) + UFD_i(t) \text{ X } B_i(t) + OC_i(t) +$$

$$\{a_{ij}(t) + b_i(t)\} \text{ X } x_{ij}(t) + \frac{x_{ij}(t)}{Q_i} \text{ x } VC_{ij}(t)$$

iii. Minimize the supply chain cost for warehouse at time t ($C_3(t)$): A warehouse's supply chain cost consists of Inventory cost, Backorder cost, Ordering cost and Distribution cost

Minimize,

$$\mathbf{C_3(t)} = INVC_i(t) + BKC_i(t) + OC_i(t) + DC_i(t)$$

$$= INV_i(t) \text{ X } H_i(t) + UFD_i(t) \text{ X } B_i(t) + OC_i(t) +$$

$$\{a_{ij}(t) + b_i(t)\} \text{ X } x_{ij}(t) + \frac{x_{ij}(t)}{Q_i} \text{ x } VC_{ij}(t)$$

iv. *Minimize the supply chain cost for factory at time t ($C_4(t)$)*: A factory's supply chain cost consists of Inventory cost, Backorder cost, Ordering cost, Distribution cost and Production cost.

Minimize,

$$\mathbf{C_4(t)} = INVC_i(t) + BKC_i(t) + OC_i(t) + DC_i(t) + PC_i(t)$$

$$= INV_i(t) \text{ X } H_i(t) + UFD_i(t) \text{ X } B_i(t) + OC_i(t) +$$

$$\{a_{ij}(t) + b_i(t)\} \text{ X } x_{ij}(t) + \frac{x_{ij}(t)}{Q_i} \text{ x } VC_{ij}(t) + D_{ij}(t) \text{ X } CU_i(t)$$

v. *Minimize the Total Supply Chain Cost (TSCC).* TSCC is the sum of all costs involved in the supply chain. If we assume the number of weeks is M then the final objective is to minimize the following.

Minimize,

$$\mathbf{TSCC} = \sum_{t=1}^{M} (C_1(t) + C_2(t) + C_3(t) + C_4(t))$$

4.5 SETTING INVENTORY POLICIES AND COSTS

The third objective is to set the inventory polices and costs associated with different expenditures. To set the inventory policies, first need to fix which inventory model to use. After that the lead time, ordering policy and beginning inventory should be set according to the characteristics of each member of each member of the supply chain network.

After setting the inventory policies, all the costs should be set. These costs includes unit holding cost, backorder cost, per unit distribution cost, per unit production cost and many more.

4.6 APPLY GENETIC ALGORITHM

When all the inputs of the process is ready, the final and last step is the application of genetic algorithm. To apply genetic algorithms all the parameters and operators are set which suit the system most and can find the optimum ordering policy for the lowest value of the objective function which is minimization of the total supply chain cost.

4.6.1. Algorithm

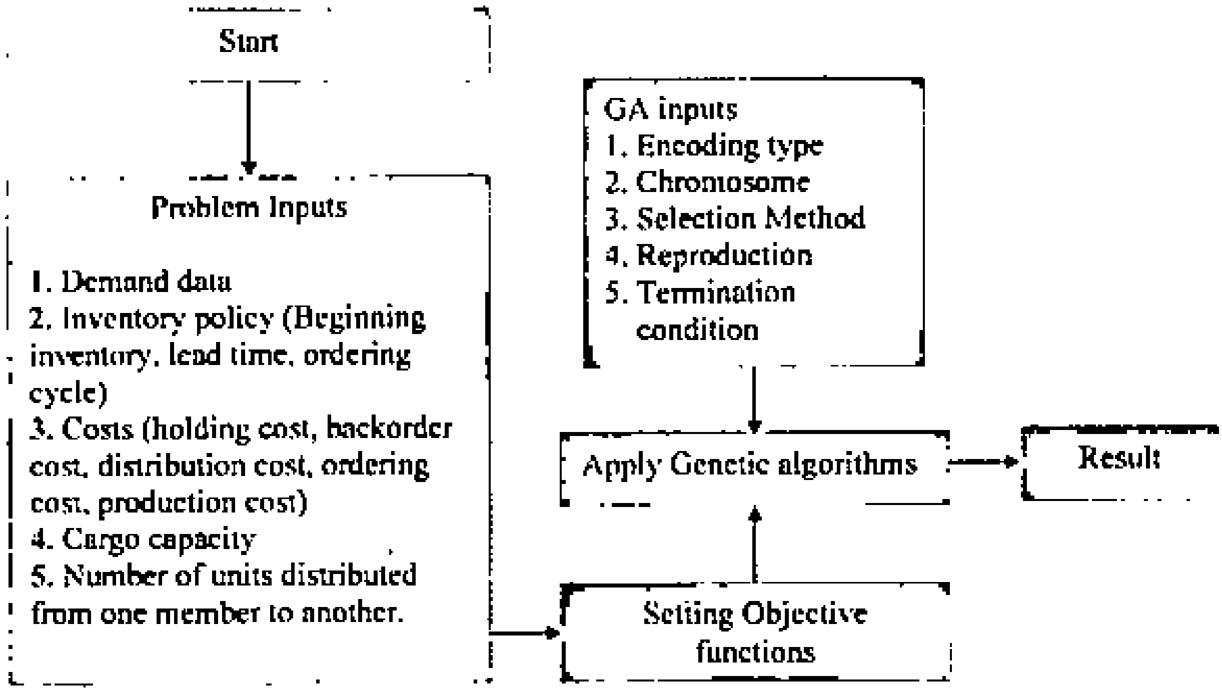

Figure 4.2: Genetic Algorithm Approach

4.6.2 Algorithm structure

Step 1: Create N number of chromosomes (extra demands for each member which are retailer, distributor, warehouse, factory) to create an initial population pool for every week. A typical chromosome is shown in figure 4.3. The initial population number is taken as computer input for the program.

3	4	23	6

Figure 4.3: A typical chromosomes

Step 2: Evaluate the objective function.

Step 3: Calculate the probability p_i and cumulative probability q_i for i chromosomes. [i is the population number]

Step 4: Select the chromosomes with some selection mechanism. Roulette wheel mechanism is used.

Step 5: Select the chromosomes as Parents which will undergo breeding to create next generation.

Step 6: Take crossover rate p_c and mutation rate p_m as computer program input. Crossover rate indicates how many chromosomes will undergo the crossover operation. Mutation rate indicates how many of the bits will undergo in change through mutation. Crossover and Mutation operations are selected randomly.

Step 7: Select randomly the chromosomes for crossover. Apply single point crossover. No. of X-over points N_{Cp} =L-1, where L= no. of members if L=3, then there are 2 points where crossover can take place.

Step 8: Select randomly the bits in chromosomes which will undergo the mutation process. The selected bits will be swapped with the adjacent bit (either earlier or later).

Step 9: A generation is complete and a new set of population (offspring) has been created.

Step 10: Evaluate the fitness function value for the new population and save the value.

Step 11: Go to step 3 until Stopping conditions are met. If there is no improvement in solution for last G generations, then show the result. G is an input taken from the program. Typical value of G = 50.

4.6.3 Encoding technique

To reduce the bullwhip effect value encoding technique is used. Here the number in each box of the chromosome represents is extra demand for each member of the supply chain.

4.6.4 Initial population

Either heuristics procedures or random criterions can be used to generate feasible strings that form the initial population. The performance of GA scheme is not as good as from the pre selected starting population as it is from a random start [51]. In this research, a random generation is allowed to create the initial population pool by changing the positions of the bits in a chromosome string.

4.6.5 Selection method

There are several common techniques for selecting the chromosomes from the initial population pool. Most common techniques are tournament selection, roulette wheel selection, rank selection etc. In this algorithm, roulette wheel selection is used. This strategy is rather elitist and makes it hard for low chromosomes to survive when there are big fitness differences among the chromosomes.

4.6.6 Crossover operation

In crossover operation the chromosomes are cut in one or more points and the cut parts are interchanged. In case of bit representation it is easy. In case of value encoding if the point is selected randomly then there is a chance of creating a repetition of operations in the new generated chromosomes. Partially matched crossover techniques solve the problem but the process is complicated.

Crossover rate p_c is used to control the number of chromosomes. Crossover rate p_c is the percentage of total chromosomes that should undergo crossover. A random number is generated between 1 and L-1 to locate the crossover points for each pairs of selected chromosomes. If even numbers are selected then it's easy to create pairs of selected chromosomes. In case of odd number of chromosomes deduct one chromosome from the selection.

4.6.7 Mutation operation

In the proposed algorithm, a variant of scramble mutation operator is used [6]. In this method, a bit is selected randomly and then swapped with the adjacent bit either predecessor or successor. A mutation rate p_m is used to control the percentage of bits on which mutation is applied.

4.6.8 Objective function

In GA the best fit solution survive over generations. Fitness of a solution hence should reflect the quality of the schedules generated in different generations applying the GA operators to regarding the objectives. The roulette wheel selection ensures the better fit solutions to survive. In the analysis, multiple objectives are considered which are aggregated to a single objective function value. The chromosomes are selected on the basis of the value of the objective function.

4.6.9 Stopping conditions

In this algorithm there are two stopping criterion,

i. No of generation
ii. No of generations without better result.

The program is terminated if any of the above two criteria occurs.

CHAPTER 5
A CASE ANALYSIS TO JUSTIFY THE METHODOLOGY

5.1 INTRODUCTION

Supply chain management is relatively a new concept in most of the business industries of Bangladesh, but the good part is, management of different companies are now being interested to achieve an effective supply chain. Since supply chain is relatively new here in our country, people are unaware of the problems like bullwhip effect as well. In order to study the bullwhip effect in the context of Bangladeshi industries, this research is performed on the basis of collected data from Nestle Bangladesh Ltd. and a superstore named Nandon This research includes one particular product of Nestle Bangladesh Ltd which is Maggi noodle.

5.2 SUPPLY CHAIN NETWORK FOR THE ASSIGNED PRODUCT

Maggi noodle is one of the very recent mandatory foods for our urban society. As people are being busier, the demand for these sort of foods is increasing day by day. As a result the production, distribution and retailing of these products are being very vast and complicated.

Nestle has its own strategy to produce and complete the supply chain of this product. It has its own central distribution center (named warehouse in this research) from where the distributors coming from the whole country takes the products. The distributors then go to the retailer shops to supply the products and from there the product reaches to the end customer. There are a number of retailers and a number of distributors. In order to make the study more applicable, the chain superstore named "Nandon" is considered as retailer and the study was conducted on the basis of that shop.

Nandon is a well known super store of Bangladesh. It has several branches in the city Dhaka. In this research three main branches of Nandon situated in Dhanmondi, Banani and Uttara are considered. So, the supply chain network studied in this research consists of 6 members: one factory, one ware house, one distributor and three retailers. It is a multistage supply chain where the products go from factory to warehouse, from warehouse to distributor and from distributor to three retailers which are basically three superstores

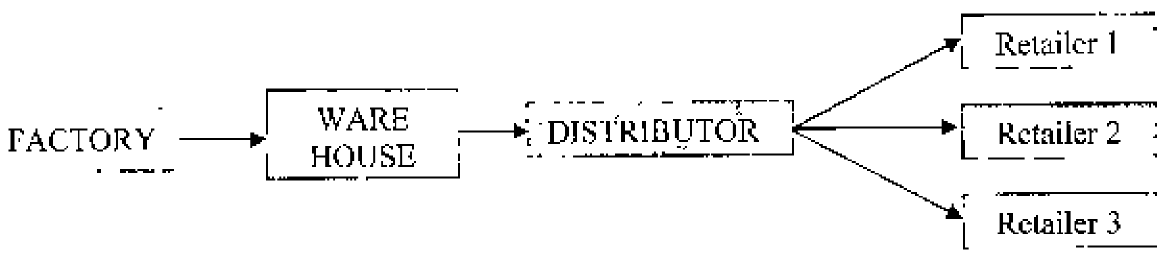

Figure 5.1: Supply Chain Network of the assigned product

5.3 DATA FROM EXISTING SYSTEM

In order to compare the approach proposed in the research with the existing situation, demand data of the customers have been collected in the form of a ranch of data for particularly year 2008.

5.3.1 Collecting Demand Data

To reduce the bullwhip effect and to find an optimal ordering policy the demand data of customers are required. The customer demand for a particular time period which is 52 weeks of year 2008 is collected. Table 5.1 shows the customer demand for the three above mentioned retailers which are randomly generated [52].

Table 5.1: Customer demand for Retailer 1, Retailer 2 and Retailer 3

Week	Customer Demand for Retailer 1	Customer Demand for Retailer 2	Customer Demand for Retailer 3	*Week*	Customer Demand for Retailer 1	Customer Demand for Retailer 2	Customer Demand for Retailer 3
1	10	17	17	*27*	15	17	18
2	11	14	16	*28*	12	15	19
3	13	15	15	*29*	11	14	13
4	14	16	16	*30*	10	17	12
5	11	17	17	*31*	12	18	15
6	15	18	21	*32*	13	19	13
7	12	19	13	*33*	14	15	15
8	10	14	17	*34*	13	14	16
9	13	16	15	*35*	10	16	14
10	15	17	11	*36*	10	15	17
11	13	15	12	*37*	12	16	13
12	15	14	13	*38*	14	15	15
13	10	16	15	*39*	13	15	16
14	11	17	13	*40*	12	16	16
15	12	14	17	*41*	11	17	13
16	14	15	12	*42*	12	15	15
17	15	19	11	*43*	14	16	13
18	12	18	15	*44*	11	17	14
19	11	15	14	*45*	12	14	13
20	10	16	16	*46*	15	15	12
21	11	17	14	*47*	12	16	16
22	10	16	17	*48*	13	17	14
23	11	18	11	*49*	14	16	15
24	12	20	10	*50*	10	16	14
25	13	14	14	*51*	12	17	12
26	14	16	13	*52*	13	15	11

5.3.2 Inventory Policies

To find the ordering quantities for the existing data, information about the inventory policies are essential. Here all the members of the supply chain have their own inventory policy except the customers.

Table 5.2: Inventory policies for each member of the supply chain

Elements	Retailer 1	Retailer 2	Retailer 3	Distributor	Warehouse	Factory
Beginning Inventory(units)	20	20	20	75	90	100
Lead time(week)	1	1	1	1	1	1
Ordering cycle (week)	1	1	1	1	1	1
Replenishment point (cases)	10	10	10	60	100	100

1. To find out the ordering policy for the members of the supply chain, a fixed amount of beginning inventory for each member of the supply chain is assumed.
2. Ordering cycle time is set according to the real scenario.
3. Lead time is also collected from real data
4. Replenishment point is different for different members. Each of the retailer keeps stock equal to one weeks' minimum demand. Distributor keeps 2 week demand of the retailers as a stock. Warehouse also keeps a twice of the average demand of the distributor and the factory keeps the stock what ever the ware house keeps.

5.3.3 Existing ordering policy

Based on the collected customer demand and the inventory policy, ordering quantities are calculated for each of the member of the supply chain by a simulation in Microsoft Excel 2003 on the basis of the following equations [3].

Order for each member = Max (0, Indicated order)

Indicated order = Demand from the immediate downstream + Adjusted Inventory Stock + Shortage quantity

Adjusted Inventory Stock = Replenishment Point – Inventory level

Table 5.3 shows the ordering quantities for each of the supply chain member of the existing system calculated from the simulation.

Table 5.3: Existing Ordering Pattern for one year for the assigned product

Week	**Retailer 1** (Units)	**Retailer 2** (Units)	**Retailer 3** (Units)	**1,2,3(total)** (Units)	**Distributor** (Units)	**Warehouse** (Units)	**Factory** (Units)
1	10	24	24	58	101	212	424
2	12	11	15	38	18	0	0
3	15	16	14	45	52	10	0
4	15	17	17	49	53	54	0
5	8	18	18	44	39	25	0
6	19	19	25	63	82	125	15
7	9	20	5	34	5	0	0
8	8	9	21	38	42	7	0
9	16	18	13	47	56	70	22
10	17	18	7	42	37	18	0
11	11	13	13	37	32	27	2
12	17	13	14	44	51	70	113

13	5	18	17	40	36	21	0
14	12	18	11	41	42	48	47
15	13	11	21	45	49	56	64
16	16	16	7	39	33	17	0
17	16	23	10	49	59	85	131
18	9	17	19	45	41	23	0
19	10	12	13	35	25	9	0
20	9	17	18	44	53	81	109
21	12	18	12	42	40	27	0
22	9	15	20	44	46	52	50
23	12	20	5	37	30	14	0
24	13	22	9	44	51	72	106
25	14	8	18	40	36	21	0
26	15	18	12	45	50	64	77
27	16	18	23	57	69	88	112
28	9	13	20	42	27	0	0
29	10	13	7	30	18	0	0
30	9	20	11	40	50	76	64
31	14	19	18	51	62	74	72
32	14	20	11	45	39	16	0
33	15	11	17	43	41	43	28
34	12	13	17	42	41	41	39
35	7	18	12	37	32	23	5
36	10	14	20	44	51	70	117
37	14	17	9	40	36	21	0
38	16	14	17	47	54	72	95
39	12	15	17	44	41	28	0
40	11	17	16	44	44	47	50
41	10	18	10	38	32	20	0
42	13	13	17	43	48	64	101
43	16	17	11	44	45	42	20

44	8	18	15	41	38	31	20
45	13	11	12	36	31	24	17
46	18	16	11	45	54	77	130
47	9	17	20	46	47	40	3
48	14	18	12	44	42	37	34
49	15	15	16	46	48	54	71
50	6	16	13	35	24	0	0
51	14	18	10	42	49	74	94
52	14	13	10	37	32	15	0

A further simulation was conducted to see what happens in the ordering policy for years 2009 just by duplicating the customer demand of 2008 for the analysis purpose. The ordering policy is shown below in table 5.4

Table 5.4: Ordering policy for year 2

Week	**Retailer 1** (Units)	**Retailer 2** (Units)	**Retailer 3** (Units)	**Retailer 1,2,3(total)** (Units)	**Distributor** (Units)	**Warehouse** (Units)	**Factory** (Units)
53	7	19	23	49	61	90	121
54	12	11	15	38	27	0	0
55	15	16	14	45	52	70	50
56	15	17	17	49	53	54	38
57	8	18	18	44	39	25	0
58	19	19	25	63	82	125	221
59	9	20	5	34	5	0	0
60	8	9	21	38	42	7	0
61	16	18	13	47	56	70	22

62	17	18	7	42	37	18	0
63	11	13	13	37	32	27	2
64	17	13	14	44	51	70	113
65	5	18	17	40	36	21	0
66	12	18	11	41	42	48	47
67	13	11	21	45	49	56	64
68	16	16	7	39	33	17	0
69	16	23	10	49	59	85	131
70	9	17	19	45	41	23	0
71	10	12	13	35	25	9	0
72	9	17	18	44	53	81	109
73	12	18	12	42	40	27	0
74	9	15	20	44	46	52	50
75	12	20	5	37	30	14	0
76	13	22	9	44	51	72	106
77	14	8	18	40	36	21	0
78	15	18	12	45	50	64	77
79	16	18	23	57	69	88	112
80	9	13	20	42	27	0	0
81	10	13	7	30	18	0	0
82	9	20	11	40	50	76	64
83	14	19	18	51	62	74	72
84	14	20	11	45	39	16	0
85	15	11	17	43	41	43	28
86	12	13	17	42	41	41	39
87	7	18	12	37	32	23	5
88	10	14	20	44	51	70	117

89	14	17	9	40	36	21	0
90	16	14	17	47	54	72	95
91	12	15	17	44	41	28	0
92	11	17	16	44	44	47	50
93	10	18	10	38	32	20	0
94	13	13	17	43	48	64	101
95	16	17	11	44	45	42	20
96	8	18	15	41	38	31	20
97	13	11	12	36	31	24	17
98	18	16	11	45	54	77	130
99	9	17	20	46	47	40	3
100	14	18	12	44	42	37	34
101	15	15	16	46	48	54	71
102	6	16	13	35	24	0	0
103	14	18	10	42	49	74	94
104	14	13	10	37	32	15	0

Note: 1 unit = 20 single packets of Maggi noodles.

The detail about this simulation is given in Appendix A.

5.3.4 Graphical representation of the existing ordering policy

Following graphs have been drawn from the existing ordering policy of each member of the supply chain for year 1 and for year 2.

5.3.4.1 Graphical representation for year 1

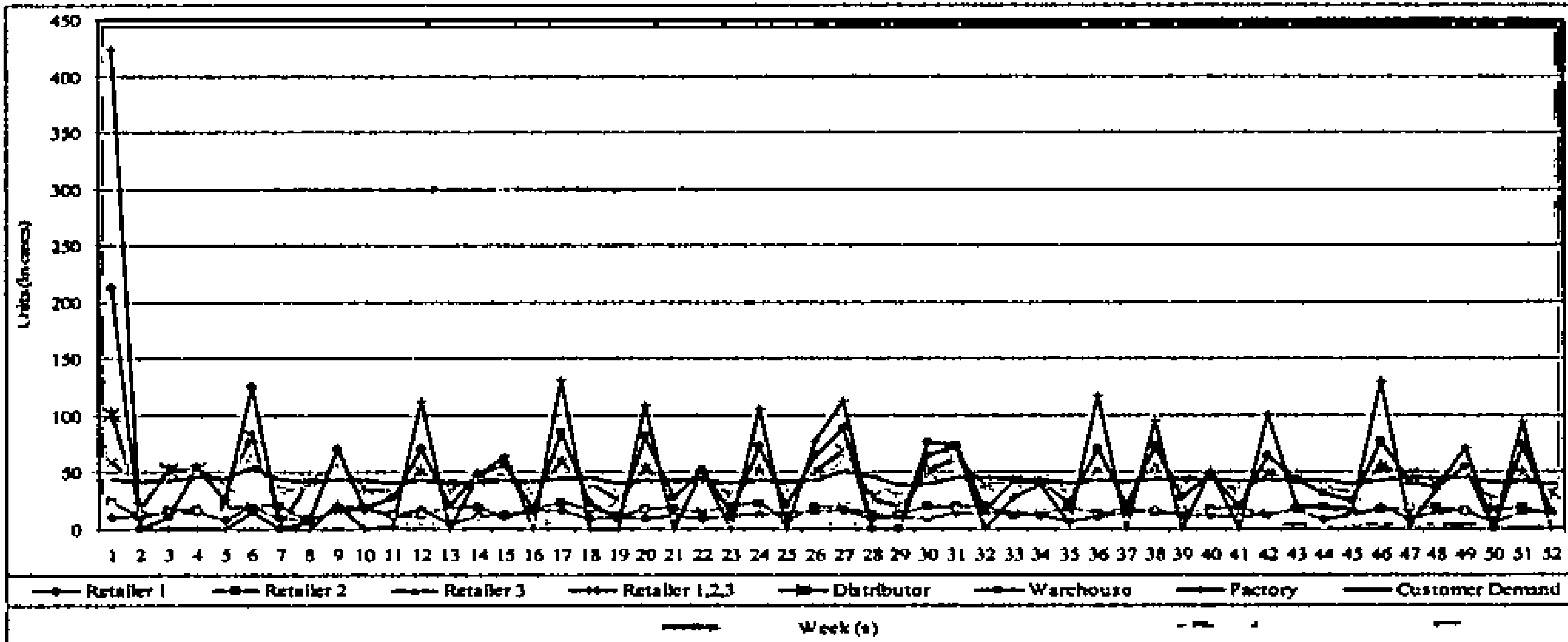

Figure 5.2: Graphical Representation of the existing ordering pattern and actual sale for each supply chain member for year 1

5.3.4.2 Graphical representation for year 1 and 2:

For the analysis purpose the following graph has been drawn from the existing ordering policy of each members of the supply chain including both year 1 and 2.

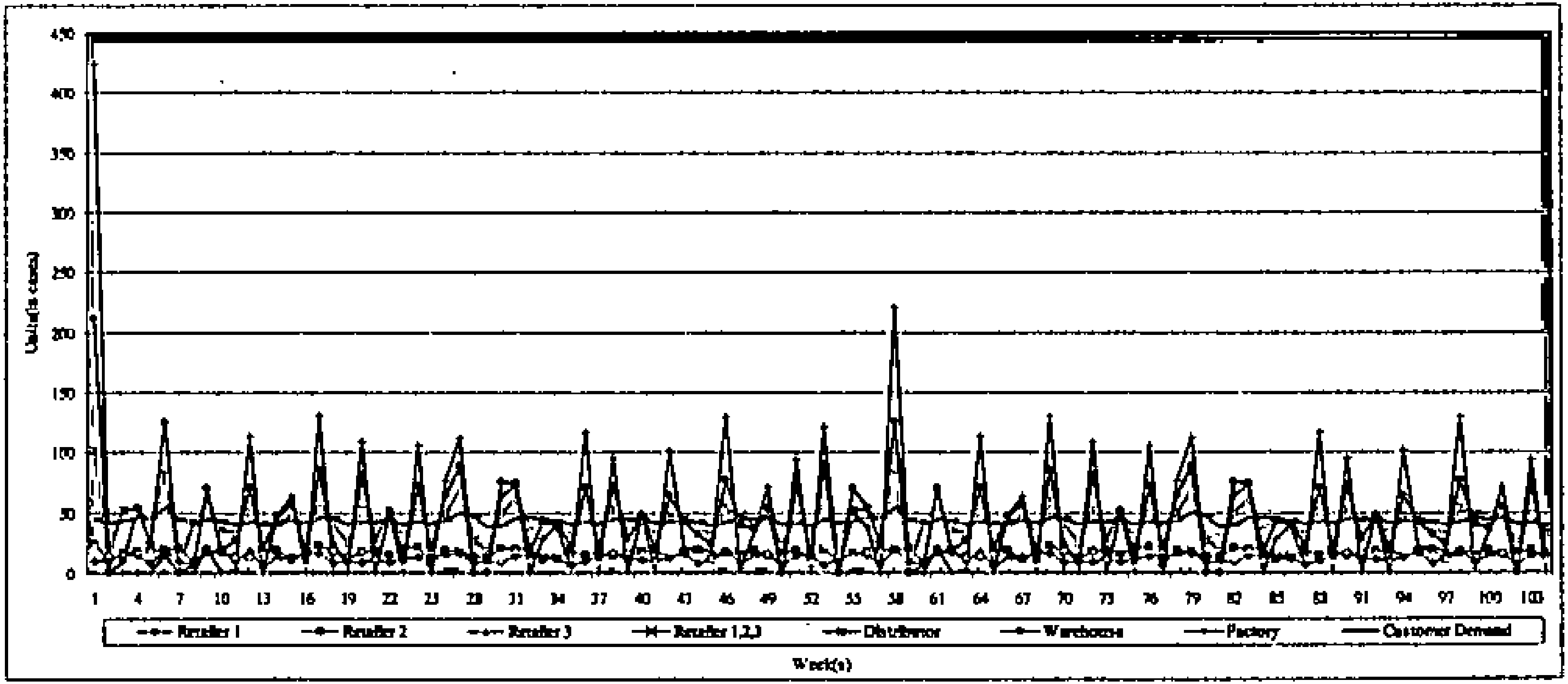

Figure 5.3: Graphical Representation of the existing ordering pattern and actual sale for each supply chain member for year 1& 2

5.4 ANALYSIS OF THE GRAPHS OF EXISTING DATA

i. The above drawn graphs 5.2 and 5.3 show the ordering quantities and customer demands for all six members of the concerned supply chain.

ii. The graphs show that there is a variation in demand for each member of the supply chain. Order varies in every week for all of the members as it moves toward the upstream of the chain which implies. order varies in greater number from the retailers to the factory.

iii. In week 1 from figure 5.2, all the members order a large amount to fulfill the demand and inventory policies. However, after week 1 ware house orders nothing for the second week. On the other hand factory also does not order anything for several weeks. Reason for this is that they have ordered so much on the first week that they don't need to order anymore to fulfill the demand for the few weeks afterwards.

iv. In few other weeks like week 31and 32 demand amplification is reduced. then again it starts and it maximize on week 64 (from graph 5.3).

v. In many weeks like week number 16, 19, the factory does not order anything, but on the next week it orders a great amount to the production line, which indicates the presence of order amplifications. Again in few other weeks the order variability is increases between distributor and ware house too.

vi. It should be clearly noticed that orders do not vary that much in the down streams of the supply chain which are the retailers. but it varies in a greater number in the up streams of the supply chain, which is clearly a symptom of bullwhip effect.

vii. After the analysis of the demand data for each member of the supply chain, it is clearly visible that *Bull Whip Effect is present* in the studied supply chain.

5.5 PROBLEMS ASSOCIATED WITH BULLWHIP EFFECT

As unnecessary demand variability complicates the supply chain planning and execution processes, the same happened in Nestle Bangladesh and Nandon too. The following undesirable effects increase in their severity as bull whip effect negatively impacts operating performances of each member of the supply chain,

i. Schedule variability increases.
ii. Capacity for each member of the supply chain (retailer 1, retailer 2, retailer 3, distributor, warehouse, and factory) is sometime under loaded, sometime overloaded.
iii. Final and the most severe problem of is that the overall costs of supply chain increases.

5.6 SOLUTION APPROACH FOR THE CASE

To reduce the bullwhip effect a detail solution techniques have already been proposed on chapter 4. Based on those techniques, the bullwhip effect of this company has been studied.

5.6.1 Setting objective function

The supply chain of the existing case consists of three retailers, a distributor, a warehouse and a factory.

The main objective is to minimize the total supply chain cost (TSCC). So the objective function Z is minimizing the total supply chain cost.

$$\mathbf{Z} = \sum_{t=1}^{M} (C_{11}(t) + C_{12}(t) + C_{13}(t) + C_2(t) + C_3(t) + C_4(t))$$

The above objective is the summation of the six other objectives which are,

i. Minimize the supply chain cost for retailer 1 at week t ($C_{11}(t)$): Retailer 1's supply chain cost consists of inventory cost, backorder cost and ordering cost.

Minimize,

$$C_{11}(t) = INVC_i(t) + BKC_i(t) + OC_i(t)$$
$$= INV_i(t) \text{ X } H_i(t) + UFD_i(t) \text{ X } B_i(t) + OC_i(t)$$

ii. Minimize the supply chain cost for retailer 2 at week t ($C_{12}(t)$): Retailer 2's supply chain cost consists of inventory cost, backorder cost and ordering cost.

Minimize,

$$C_{12}(t) = INVC_i(t) + BKC_i(t) + OC_i(t)$$
$$= INV_i(t) \text{ X } H_i(t) + UFD_i(t) \text{ X } B_i(t) + OC_i(t)$$

iii. Minimize the supply chain cost for retailer 3 at week t ($C_{13}(t)$): Retailer 3's supply chain cost consists of inventory cost, backorder cost and ordering cost.

Minimize,

$$C_{13}(t) = INVC_i(t) + BKC_i(t) + OC_i(t)$$
$$= INV_i(t) \text{ X } H_i(t) + UFD_i(t) \text{ X } B_i(t) + OC_i(t)$$

iv. Minimize the supply chain cost for distributor at week t ($C_2(t)$): Distributor's supply chain cost consists of inventory cost, backorder cost, ordering cost and distribution cost.

Minimize,

$$C_2(t) = INVC_i(t) + BKC_i(t) + OC_i(t) + DC_i(t)$$

$$= INV_i(t) \times H_i(t) + UFD_i(t) \times B_i(t) + OC_i(t) + \{a_{ij}(t) + b_i(t)\} \times x_{ij}(t) + \frac{x_{ij}(t)}{Q_i} \times VC_{ij}(t)$$

v. Minimize the supply chain cost for warehouse at week t ($C_3(t)$): Warehouse's supply chain cost consists of inventory cost, backorder cost, ordering cost and distribution cost.

Minimize,

$$C_3(t) = INVC_i(t) + BKC_i(t) + OC_i(t) + DC_i(t)$$

$$= INV_i(t) \times H_i(t) + UFD_i(t) \times B_i(t) + OC_i(t) + \{a_{ij}(t) + b_i(t)\} \times x_{ij}(t) + \frac{x_{ij}(t)}{Q_i} \times VC_{ij}(t)$$

vi. Minimize the supply chain cost for factory at week t ($C_4(t)$): Factory's supply chain cost consists of inventory cost, backorder cost, ordering cost, distribution cost and production cost.

Minimize,

$$C_4(t) = INVC_i(t) + BKC_i(t) + OC_i(t) + DC_i(t) + PC_i(t)$$

$$= INV_i(t) \times H_i(t) + UFD_i(t) \times B_i(t) + OC_i(t) + \{a_{ij}(t) + b_i(t)\} \times x_{ij}(t) + \frac{x_{ij}(t)}{Q_i} \times VC_{ij}(t) + D_{ij}(t) \times CU_i(t)$$

5.6.2 Setting Inventory Policies and Costs

5.6.2.1 Inventory Policy

To reduce bullwhip effect a detail inventory policy must be set. In order to reduce the order amplification *Fixed Order Interval Model* for inventory policy was chosen. In fixed order interval model, orders are placed at a fixed interval.

5.6.2.2 Associated costs determination

After setting the inventory policies the next step is to fix different costs and other values associated with the supply chain for each of the member. Table 5.5 has all the values needed for the cost functions. These costs and other parameters are collected from extensive study of each member of the supply chain network.

Table 5.5: Different costs associated in the supply chain

Elements	Retailer 1	Retailer 2	Retailer 3	Distributor	Warehouse	Factory
Unit Holding Cost (Hi)	Hi= 2 Tk/case	Hi= 2 Tk/case	Hi= 2 Tk/case	Hi= 1.5 Tk/case	Hi= 1 Tk/case	Hi= 1 Tk/case
Unit Back order cost(B_i)	20 Tk/case	20 Tk/case	20 Tk/case	20 Tk/case	20 Tk/case	20 Tk/case
Ordering cost (R_i)	35Tk.	37 Tk.	40 Tk.	35 Tk.	38 Tk.	80 Tk.
Unit price of the item (b_i)	--	--	--	b_2= 220 Tk/case	b_3=200 Tk/case	b_4=180 Tk/case

unit shipping cost (a_{ij})	--	--	--	Tk 4	Tk. 4	Tk.11
cargo capacity (Q_i)	--	--	--	400 units	400 units	200 units
cost of per cargo shipping (VC_{ij})	--	--	--	1100 Tk.	400 Tk.	60 Tk.
production unit cost price(CU)	--	--	--	--	--	160 Tk./case

5.6.3 Apply Genetic Algorithm

5.6.3.1 Setting Chromosomes

In order to apply genetic algorithm, the chromosomes first have to be set. Figure 5.4 shows a typical chromosome for the supply chain consists of three retailers, one distributor, one warehouse, and one factory for one week Here chromosome indicate the extra demands which are ordered by each of the member of the supply chain in addition to their real demand.

Retailer 1	Retailer 2	Retailer 3	Distributor	Warehouse	Factory
3	2	5	10	14	10

Figure 5.4: A typical chromosome for week 1

Genetic algorithm is applied for 52 weeks. So, chromosomes for 52 weeks which are the input to the program are shown in Table 5.6.

Table 5.6: Chromosome inputs for 52 weeks

Week	Retailer 1	Retailer 2	Retailer 3	Distributor	Warehouse	Factory
1	3	2	5	10	14	10
2	3	5	3	15	5	6
3	4	5	2	8	6	5
4	6	4	2	7	5	4
5	4	4	6	8	0	10
6	3	6	9	5	10	12
7	2	5	3	4	5	10
8	2	2	5	2	5	5
9	2	2	6	9	5	7
10	0	6	9	13	10	3
11	7	9	5	13	14	11
12	9	8	7	20	7	3
13	11	5	3	8	9	6
14	9	10	4	7	9	6
15	4	4	6	8	0	10
16	3	6	9	5	10	12
17	2	5	3	4	5	10
18	7	8	6	9	10	5
19	6	7	7	8	15	10
20	10	8	9	11	10	13
21	3	2	5	0	14	10
22	3	5	3	15	5	6
23	4	5	2	8	6	5
24	6	4	2	7	5	4
25	4	4	6	8	0	10

26	3	6	9	5	10	12
27	2	5	3	4	5	10
28	9	12	7	12	5	9
29	2	2	6	9	5	8
30	5	6	9	13	9	3
31	3	2	5	10	14	10
32	3	5	3	15	5	6
33	4	5	2	8	6	5
34	6	4	2	7	5	4
35	4	4	6	8	0	10
36	3	6	9	5	10	12
37	2	5	3	4	5	10
38	2	2	5	2	5	5
39	2	2	6	9	5	7
40	0	6	9	13	10	3
41	3	2	5	10	14	10
42	3	5	3	15	5	6
43	4	5	2	8	6	5
44	6	4	2	7	5	4
45	4	4	6	8	0	10
46	3	6	9	5	10	12
47	12	15	3	6	8	10
48	2	2	5	2	5	5
49	2	2	6	9	5	7
50	9	6	9	13	10	3
51	3	2	5	10	14	10
52	3	5	3	15	5	6

5.6.3.2 Assumption

In order to find the optimal ordering policy a number of simulations are conducted where the extra demand of each member should not be more than 25 units. It implies that the extra amount can vary from 0 to 25 unit(s) along with the actual demand of each member. A further analysis is conducted where the extra demand is allowed to vary from 0 to 10 unit(s).

5.6.3.3 Genetic Algorithm Parameters

Three different generation numbers (1000, 10000, 20000) are tested where various combinations of other parameter such as initial population (40. 80), crossover rate (0.25, 0.5) and mutation rate (0.5, 1) are also used.

CHAPTER 6
RESULTS OF THE ANALYSIS

6.1 INTRODUCTION

The analysis is conducted with the help of DEV C++ version 4.9.9.0 and Microsoft Excel 2003. Different parameters of Genetic algorithm have been applied, a number of combinations have been tried to find out the optimal ordering policy which will have the minimum cost. Genetic algorithm finds the extra ordering quantities for all the six members and costs for each weeks as well as the total supply chain cost for all the six members.

6.2 RESULTS OF THE ANALYSIS

Two different sets of analysis are done where in the first analysis chromosomes can vary from 0 to 25 and in the second analysis chromosomes vary from 0 to 10, which are categorized as

i. Analysis 1 (Chromosomes between 0 -25)
ii. Analysis 2 (Chromosomes between 0-10)

6.2.1 Results of analysis 1

The following table 6.1 shows the value of Z obtained by applying genetic algorithm with various combinations of parameters and where the chromosomes are set to vary from 0 to 25. In this analysis the parameter are set to generation (1000, 10000, 20000), population (40, 80), crossover (0.25, 0.5), mutation (0.5, 1).

Table 6.1 Values of Z with different GA parameters and chromosomes from 0-25

Attempt	Generation	Population	Cross over	Mutation	Value of Z (Total Supply chain cost for a year) Tk.
1	1000	40	0.25	0.5	21,64,627
2				1	21,06,701
3			0.5	0.5	20,98,964.75
4				1	20,94,602.5
5		80	0.25	0.5	7,13,728.9
6				1	6,60,109.8125
7			0.5	0.5	6,93,917.3125
8				1	7,08,283.125
9	10000	40	0.25	0.5	21,55,319.25
10				1	21,32,412.25
11			0.5	0.5	20,92,085.75
12				1	21,07,950.5
13		80	0.25	0.5	7,53,025.6875
14				1	6,79,613.875
15			0.5	0.5	6,74,297
16				1	6.71,1687.125
17	20000	40	0.25	0.5	22,55,772.25
18				1	21,37,603
19			0.5	0.5	22,03,070
20				1	21,21,408.75
21		80	0.25	0.5	7,29,551.375
22				1	6,96,976.5
23			0.5	0.5	6.95,449.75
24				1	6,72,637.5

6.2.1.1 Best Result of Analysis 1

The best result of the combinations for analysis 1 is the following one. where

Generation: 1000

Number of Initial Population: 80

Selection Method: Roulette wheel method

Cross over type: Single point crossover

Cross Over value: 0.25

Mutation value:1

Value of Z : Tk. 6,60.109.8125 per year

Stopping condition where best value did not change is G: 50

6.2.1.2 Ordering policy obtained from analysis 1

To find out the optimal ordering quantities for each member of the supply chain, the results of genetic algorithm (required extra ordering quantities for each member) are obtained from the program.

The values of the extra ordering quantity required for each member obtained from the genetic algorithm are shown in table 6.2 when,

Generation	Population	Cross Over	Mutation Rate
1000	80	0.25	1

Table 6.2: Extra ordering quantities obtained from genetic algorithm for analysis 1

Week	Retailer 1	Retailer 2	Retailer 3	Distributor	Warehouse	Factory
1	*0*	*1*	*3*	*1*	*0*	*4*
2	*1*	*0*	*1*	*0*	*0*	*18*
3	*0*	*2*	*2*	*0*	*3*	*12*
4	*0*	*0*	*0*	*0*	*5*	*1*
5	*5*	*0*	*4*	*0*	*6*	*0*
6	*0*	*0*	*3*	*1*	*6*	*12*
7	*0*	*1*	*4*	*2*	*3*	*0*
8	*3*	*1*	*1*	*4*	*1*	*9*
9	*0*	*3*	*0*	*1*	*7*	*0*

10	2	0	6	2	4	5
11	3	0	1	7	1	4
12	2	2	0	0	4	10
13	5	1	3	0	6	8
14	0	6	3	0	1	0
15	0	1	4	1	0	11
16	1	2	1	1	2	4
17	4	1	6	1	3	0
18	1	0	0	1	1	0
19	1	0	3	2	4	0
20	0	3	1	2	3	1
21	0	0	0	3	5	15
22	0	7	2	1	2	2
23	1	1	2	1	9	3
24	0	0	5	1	6	4
25	2	0	0	2	8	1
26	1	0	2	5	0	0
27	3	4	3	0	4	1
28	2	0	0	4	9	4
29	7	0	1	2	3	2
30	0	1	1	4	3	12
31	0	1	5	0	3	10
32	0	0	7	0	7	7
33	7	2	2	0	1	3
34	0	7	0	0	5	11
35	1	0	0	0	5	15
36	0	8	0	0	1	4
37	7	0	0	1	0	8
38	1	2	1	1	0	16
39	4	0	0	0	3	1
40	0	1	2	0	5	1
41	0	0	1	3	3	21
42	3	1	3	2	0	12
43	2	4	2	0	1	12
44	0	1	2	1	6	4
45	2	5	2	1	5	6
46	0	0	4	0	0	4
47	0	5	1	0	1	0
48	2	1	1	0	4	1
49	4	2	5	1	0	7
50	4	0	0	2	6	3
51	0	2	0	1	8	12
52	6	8	0	0	13	17

Based on the above extra ordering quantities and expected customer demand data, the optimal ordering quantities for each supply chain member has been calculated by putting these values in to the simulation shown in table 6.3.

Table 6.3 Optimal ordering quantities for supply chain member for analysis I

WEEK	Retailer 1			Retailer 2			Retailer 3			Distributor			Ware house		Factory		*Total supply chain cost (1k.)*
	Customer Demand	*Extra*	**Order** (to distributor)	**Customer Demand**	*Extra*	**Order** (to distibutor)	**Customer Demand**	*Extra*	**Order** (to distributor)	**Demand from retailer 1,2,3**	*Extra*	**Order** (to warehouse)	*Extra*	**Order** (to factory)	*Extra*	**Order** (to production line)	
1	10	*0*	**10**	17	*1*	**18**	17	*3*	**20**	48	*1*	**49**	*0*	**49**	*4*	**53**	14618.25
2	11	*1*	**12**	14	*0*	**14**	16	*1*	**17**	43	*0*	**43**	*0*	**43**	*18*	**61**	7934.5
3	13	*0*	**13**	15	*2*	**17**	15	*2*	**17**	47	*0*	**47**	*3*	**50**	*12*	**62**	9287.7002
4	14	*0*	**14**	16	*0*	**16**	16	*0*	**16**	46	*0*	**46**	*5*	**51**	*1*	**52**	5520.7998
5	11	*5*	**16**	17	*0*	**17**	17	*4*	**21**	54	*0*	**54**	*6*	**60**	*0*	**60**	11433.25
6	15	*0*	**15**	18	*0*	**18**	21	*3*	**24**	57	*1*	**58**	*6*	**64**	*12*	**76**	10741.6
7	12	*0*	**12**	19	*1*	**20**	13	*4*	**17**	49	*2*	**51**	*3*	**54**	*0*	**54**	9185.25
8	10	*3*	**13**	14	*1*	**15**	17	*1*	**18**	46	*4*	**50**	*1*	**51**	*9*	**60**	11432.45
9	13	*0*	**13**	16	*3*	**19**	15	*0*	**15**	47	*1*	**48**	*7*	**55**	*0*	**55**	9043.2998
10	15	*2*	**17**	17	*0*	**17**	11	*6*	**17**	51	*2*	**53**	*4*	**57**	*5*	**62**	12697.2
11	13	*3*	**16**	15	*0*	**15**	12	*1*	**13**	44	*7*	**51**	*1*	**52**	*4*	**56**	12102.05
12	15	*2*	**17**	14	*2*	**16**	13	*0*	**13**	46	*0*	**46**	*4*	**50**	*10*	**60**	10250.4
13	10	*5*	**15**	16	*1*	**17**	15	*3*	**18**	50	*0*	**50**	*6*	**56**	*8*	**64**	13925.65
14	11	*0*	**11**	17	*6*	**23**	13	*3*	**16**	50	*0*	**50**	*1*	**51**	*0*	**51**	10530.75
15	12	*0*	**12**	14	*1*	**15**	17	*4*	**21**	48	*1*	**49**	*0*	**49**	*11*	**60**	10476.6
16	14	*1*	**15**	15	*2*	**17**	12	*1*	**13**	45	*1*	**46**	*2*	**48**	*4*	**52**	9424.0498
17	15	*4*	**19**	19	*1*	**20**	11	*6*	**17**	56	*1*	**57**	*3*	**60**	*0*	**60**	13520.5
18	12	*1*	**13**	18	*0*	**18**	15	*0*	**15**	46	*1*	**47**	*1*	**48**	*0*	**48**	6594.3999
19	11	*1*	**12**	15	*0*	**15**	14	*3*	**17**	44	*2*	**46**	*4*	**50**	*0*	**50**	10450.5
20	10	*0*	**10**	16	*3*	**19**	16	*1*	**17**	46	*2*	**48**	*3*	**51**	*1*	**52**	10432.5
21	11	*0*	**11**	17	*0*	**17**	14	*0*	**14**	42	*3*	**45**	*5*	**50**	*15*	**65**	12141.15
22	10	*0*	**10**	16	*7*	**23**	17	*2*	**19**	52	*1*	**53**	*2*	**55**	*2*	**57**	12935.7
23	11	*1*	**12**	18	*1*	**19**	11	*2*	**13**	44	*1*	**45**	*9*	**54**	*3*	**57**	12871.85
24	12	*0*	**12**	20	*0*	**20**	10	*5*	**15**	47	*1*	**48**	*6*	**54**	*4*	**58**	12584.3
25	13	*2*	**15**	14	*0*	**14**	14	*0*	**14**	43	*2*	**45**	*8*	**53**	*1*	**54**	11645.9
26	14	*1*	**15**	16	*0*	**16**	13	*2*	**15**	46	*5*	**51**	*0*	**51**	*0*	**51**	10902.4

27	15	3	18	17	4	21	18	3	21	60	0	60	4	64	1	65	14030
28	12	2	14	15	0	15	19	0	19	48	4	52	9	61	4	65	14265.2
29	11	7	18	14	0	14	13	1	14	46	2	48	3	51	2	53	14092
30	10	0	10	17	1	18	12	1	13	41	4	45	3	48	12	60	13657 8
31	12	0	12	18	1	19	15	5	20	51	0	51	3	54	10	64	13393 2
32	13	0	13	19	0	19	13	7	20	52	0	52	7	59	7	66	15144 55
33	14	7	21	15	2	17	15	2	17	55	0	55	1	56	3	59	14579.75
34	13	0	13	14	7	21	16	0	16	50	0	50	5	55	11	66	15298.15
35	10	1	11	16	0	16	14	0	14	41	0	41	5	46	15	61	12409.05
36	10	0	10	15	8	23	17	0	17	50	0	50	1	51	4	55	13209.9
37	12	7	19	16	0	16	13	0	13	48	1	49	0	49	8	57	13665.8
38	14	1	15	15	2	17	15	1	16	48	1	49	0	49	16	65	13393 05
39	13	4	17	15	0	15	16	0	16	48	0	48	3	51	1	52	11153.4
40	12	0	12	16	1	17	16	2	18	47	0	47	5	52	1	53	11447 95
41	11	0	11	17	0	17	13	1	14	42	3	45	3	48	21	69	15259.4
42	12	3	15	15	1	16	15	3	18	49	2	51	0	51	12	63	15572.05
43	14	2	16	16	4	20	13	2	15	51	0	51	1	52	12	64	15435.3
44	11	0	11	17	1	18	14	2	16	45	1	46	6	52	4	56	13458.2
45	12	2	14	14	5	19	13	2	15	48	1	49	5	54	6	60	17308.801
46	15	0	15	15	0	15	12	4	16	46	0	46	0	46	4	50	11300.4
47	12	0	12	16	5	21	16	1	17	50	0	50	1	51	0	51	12353.6
48	13	2	15	17	1	18	14	1	15	48	0	48	4	52	1	53	12549 7
49	14	4	18	16	2	18	15	5	20	56	1	57	0	57	7	64	17222 699
50	10	4	14	16	0	16	14	0	14	44	2	46	6	52	3	55	15237
51	12	0	12	17	2	19	12	0	12	43	1	44	8	52	12	64	16011.15
52	13	6	19	15	8	23	11	0	11	53	0	53	13	66	17	83	25978.699

Total supply chain cost (Tk) =660109.8

The above table shows the best optimal ordering policy for the combination when generation is 1000, population is 80. cross over rate 0.25 and mutation rate is 1. The others ordering policies for some other combinations are shown in Appendix B.

6.2.1.3 Graphical presentation of analysis 1

The above ordering quantities are plotted in the following figure 6.1

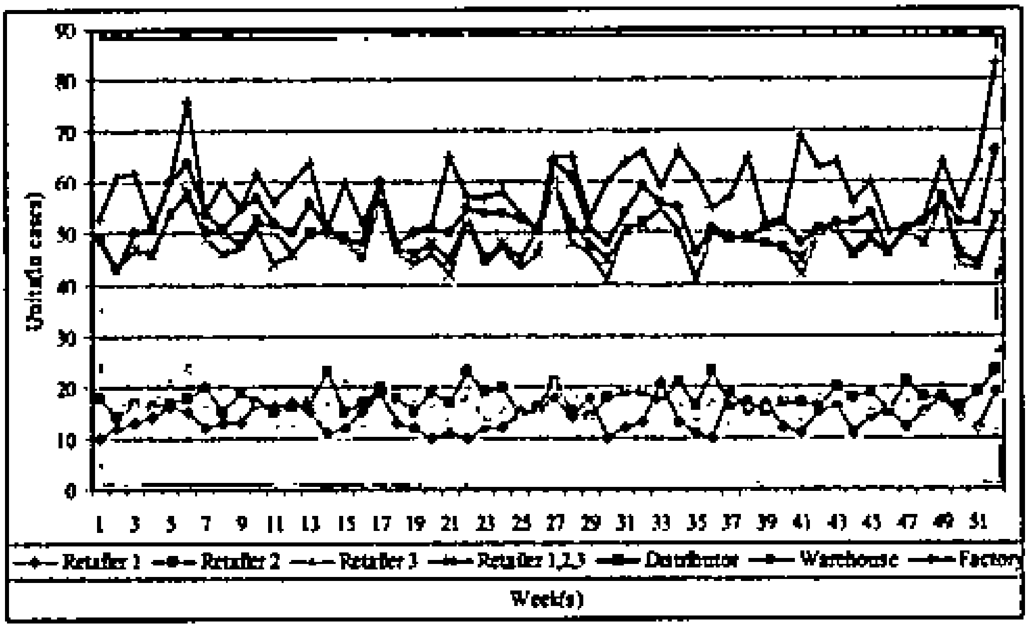

Figure 6.1: Graphical presentation of ordering policy for analysis 1

6.2.2 Results of analysis 2

In analysis 2, the values of Z are obtained by applying genetic algorithm with various combinations of parameters and where the chromosomes are set to vary from 0 to 10. In this analysis the parameter are set to generation (1000, 10000, 20000), population (40, 80), crossover (0.25, 0.5), mutation (0.5, 1) and chromosome limit from 0-10. Following table 6.4 shows the values of Z for different combinations of the parameters.

Table 6.4 Values of Z with different GA parameters and chromosomes from 0-10

Attempt	Generation	Population	Cross over	Mutation	Value of Z (Total Supply chain cost for a year) Tk.
1	1000	40	0.25	0.5	1852475.6
2	1000	40	0.25	1	1813773
3	1000	40	0.5	0.5	1815220.75
4	1000	40	0.5	1	1788508.5
5	1000	80	0.25	0.5	428484.875
6	1000	80	0.25	1	413134.8125
7	1000	80	0.5	0.5	419791.03
8	1000	80	0.5	1	434006.56
9	10000	40	0.25	0.5	1812650.75
10	10000	40	0.25	1	1787057.5
11	10000	40	0.5	0.5	1792674
12	10000	40	0.5	1	1803785.375
13	10000	80	0.25	0.5	447339.53
14	10000	80	0.25	1	419976
15	10000	80	0.5	0.5	435795.75
16	10000	80	0.5	1	412732.31
17	20000	40	0.25	0.5	1830956
18	20000	40	0.25	1	1800699.37
19	20000	40	0.5	0.5	1808307
20	20000	40	0.5	1	1803682.62
21	20000	80	0.25	0.5	427885.2
22	20000	80	0.25	1	411746.968
23	20000	80	0.5	0.5	424322.28
24	20000	80	0.5	1	403981.15

6.2.2.1 Best Result of Analysis 2

The best result of the combinations for analysis 2 is the following one, where

Generation: 20000

Number of Initial Population: 80

Selection Method: Roulette wheel method

Cross over type: Single point crossover

Cross Over value: 0.5

Mutation value: 1

Value of Z: Tk. 403981.15 per year

Stopping condition where best value did not change is G: 50

6.2.2.2 Ordering policy obtained from analysis 2

The extra ordering quantity obtained from genetic algorithm for 52 weeks are given in table 6.2. when,

Generation	Population	Cross Over	Mutation Rate
20000	80	0.5	1

Table 6.5: Extra ordering quantities for analysis 2

Week	Retailer 1	Retailer 2	Retailer 3	Distributor	Warehouse	Factory
1	0	1	0	0	0	3
2	1	0	0	1	1	2
3	0	0	0	0	0	6
4	0	1	0	0	0	1
5	1	0	0	4	4	0
6	1	0	0	0	0	4
7	1	1	0	0	0	6
8	2	0	0	0	0	1
9	0	0	2	0	0	0
10	0	1	0	2	2	1
11	1	0	0	0	0	0
12	0	3	0	1	1	0
13	2	0	0	1	1	0
14	0	1	0	0	0	1
15	0	1	0	0	0	2

16	1	1	0	0	0	0
17	1	0	0	0	0	0
18	2	1	0	0	0	2
19	0	1	0	2	2	2
20	0	0	0	0	0	5
21	0	0	2	1	1	1
22	1	0	0	1	1	5
23	1	0	1	1	1	1
24	0	0	1	0	0	1
25	0	0	0	1	1	1
26	0	0	4	0	0	0
27	0	1	0	1	1	1
28	0	0	0	0	0	6
29	0	1	0	1	1	4
30	1	0	0	2	2	2
31	1	0	0	3	3	2
32	2	0	0	1	1	2
33	0	0	0	1	1	7
34	1	3	0	0	0	3
35	0	0	0	2	2	2
36	0	0	0	4	4	1
37	0	0	0	0	0	3
38	0	0	0	1	1	2
39	1	1	0	0	0	3
40	0	0	0	1	1	3
41	0	0	1	2	2	0
42	0	1	0	2	2	0
43	0	1	0	1	1	2
44	0	0	1	3	3	3
45	0	0	2	0	0	2
46	1	0	0	3	3	0
47	2	1	0	1	1	0
48	0	0	0	4	4	2
49	1	0	0	2	2	0
50	1	0	1	0	0	1
51	2	0	0	0	0	7
52	1	4	2	1	1	2

These values of the chromosomes are then put into the simulation [53] shown in table 6.6 to calculate the optimal ordering policy.

Table 6.6 Optimal ordering quantities for supply chain member from analysis 2

WEEK	Retailer 1			Retailer 2			Retailer 3			Distributor			Ware house		Factory		Total supply chain cost (Tk.)
	Customer Demand	Extra	Order (to distributor)	Customer Demand	Extra	Order (to distributor)	Customer Demand	Extra	Order (to distributor)	Demand from retailer 1,2,3	Extra	Order (to warehouse)	Extra	Order (to factory)	Extra	Order (to production line)	
1	10	0	10	17	1	18	17	0	17	45	0	45	0	45	3	48	3673.8
2	11	1	12	14	0	14	16	0	16	42	0	42	1	43	2	45	4614.9502
3	13	0	13	15	0	15	15	1	16	44	0	44	0	44	6	50	5057.8501
4	14	0	14	16	1	17	16	1	17	48	0	48	0	48	1	49	4779.3999
5	11	1	12	17	0	17	17	0	17	46	0	46	4	50	0	50	5628.25
6	15	1	16	18	0	18	21	0	21	55	0	55	0	55	4	59	4923.25
7	12	1	13	19	1	20	13	0	13	46	0	46	0	46	6	52	6014.8999
8	10	2	12	14	0	14	17	0	17	43	0	43	0	43	1	44	5104.3999
9	13	0	13	16	0	16	15	0	15	44	2	46	0	46	0	46	5000.1001
10	15	0	15	17	1	18	11	1	12	45	0	45	2	47	1	48	6117
11	13	1	14	15	0	15	12	2	14	43	0	43	0	43	0	43	5921.1499
12	15	0	15	14	3	17	13	0	13	45	0	45	1	46	0	46	6495.4502
13	10	2	12	16	0	16	15	0	15	43	0	43	1	44	0	44	5998.3999
14	11	0	11	17	1	18	13	1	14	43	0	43	0	43	1	44	5936.3999
15	12	0	12	14	1	15	17	1	18	45	0	45	0	45	2	47	6229.7002
16	14	1	15	15	1	16	12	0	12	43	0	43	0	43	0	43	5974.1001
17	15	1	16	19	0	19	11	1	12	47	0	47	0	47	0	47	6056.1001
18	12	2	14	18	1	19	15	0	15	48	0	48	0	48	2	50	7210.75
19	11	0	11	15	1	16	14	0	14	41	0	41	2	43	2	45	6907.25
20	10	0	10	16	0	16	16	0	16	42	0	42	0	42	5	47	6250.5
21	11	0	11	17	0	17	14	0	14	42	2	44	1	45	1	46	7215.7002
22	10	1	11	16	0	16	17	1	18	45	0	45	1	46	5	51	8101.8999
23	11	1	12	18	0	18	11	0	11	41	1	42	1	43	1	44	7417.7002
24	12	0	12	20	0	20	10	1	11	43	1	44	0	44	1	45	7106.3999
25	13	0	13	14	0	14	14	0	14	41	0	41	1	42	1	43	6351.6001
26	14	0	14	16	0	16	13	0	13	43	4	47	0	47	0	47	8395.2002
27	15	0	15	17	1	18	18	1	19	52	0	52	1	53	1	54	7818.7002
28	12	0	12	15	0	15	19	1	20	47	0	47	0	47	6	53	7935.8501
29	11	0	11	14	1	15	13	0	13	39	0	39	1	40	4	44	8040.5498

30	10	*1*	**11**	17	*0*	**17**	12	*2*	**14**	42	*0*	**42**	*2*	**44**	*2*	**46**	9449.3496
31	12	*1*	**13**	18	*0*	**18**	15	*1*	**16**	47	*0*	**47**	*3*	**50**	*2*	**52**	9338.5996
32	13	*2*	**15**	19	*0*	**19**	13	*0*	**13**	47	*0*	**47**	*1*	**48**	*2*	**50**	8653
33	14	*0*	**14**	15	*0*	**15**	15	*0*	**15**	44	*0*	**44**	*1*	**45**	*7*	**52**	8455.4004
34	13	*1*	**14**	14	*3*	**17**	16	*0*	**16**	47	*0*	**47**	*0*	**47**	*3*	**50**	9879.0996
35	10	*0*	**10**	16	*0*	**16**	14	*2*	**16**	42	*0*	**42**	*2*	**44**	*2*	**46**	9328.2998
36	10	*0*	**10**	15	*0*	**15**	17	*0*	17	42	*0*	**42**	*4*	**46**	*1*	**47**	8808.5
37	12	*0*	**12**	16	*0*	**16**	13	*1*	**14**	42	*0*	**42**	*0*	**42**	*3*	**45**	8310.9502
38	14	*0*	**14**	**15**	*0*	**15**	15	*0*	**15**	44	*0*	**44**	*1*	**45**	*2*	**47**	7950.8999
39	13	*1*	**14**	15	*1*	**16**	16	*1*	**17**	47	*0*	**47**	*0*	**47**	*3*	**50**	9718.0198
40	12	*0*	**12**	16	*0*	**16**	16	*0*	16	44	*0*	**44**	*1*	**45**	*3*	**48**	8360 2002
41	11	*0*	**11**	17	*0*	17	13	*1*	**14**	42	*1*	**43**	*2*	**45**	*0*	**45**	9549 7002
42	12	*0*	**12**	15	*1*	16	15	*0*	**15**	43	*0*	**43**	*2*	**45**	*0*	**45**	9034 6504
43	14	*0*	**14**	16	*1*	**17**	13	*0*	**13**	44	*0*	**44**	*1*	**45**	*2*	47	9112.9502
44	11	*0*	**11**	17	*0*	**17**	14	*0*	**14**	42	*1*	**43**	*3*	**46**	*3*	**49**	10188.85
45	12	*0*	**12**	14	*0*	**14**	13	*0*	**13**	39	*2*	**41**	*0*	**41**	*2*	**43**	9526 7002
46	15	*1*	**16**	15	*0*	**15**	12	*0*	**12**	43	*0*	**43**	*3*	**46**	*0*	**46**	9840 9502
47	12	*2*	**14**	16	*1*	**17**	16	*0*	**16**	47	*0*	**47**	*1*	**48**	*0*	**48**	10472 45
48	13	*0*	**13**	17	*0*	**17**	14	*0*	**14**	44	*0*	**44**	*4*	**48**	*2*	**50**	10234.8
49	14	*1*	**15**	16	*0*	**16**	15	*1*	**16**	47	*0*	47	*2*	**49**	*0*	**49**	10396.7
50	10	*1*	**11**	16	*0*	**16**	**14**	*0*	**14**	41	*1*	**42**	*0*	**42**	*1*	**43**	9953.4004
51	12	*2*	**14**	17	*0*	**17**	12	*0*	**12**	43	*0*	43	*0*	**43**	*7*	**50**	11232.2
52	13	*1*	**14**	15	*4*	**19**	11	*0*	**11**	44	*2*	46	*1*	**47**	*2*	**49**	13908.25

Total supply chain cost (Tk)= 4,03,981.15

The above table shows the best optimal ordering policy for the combination when generation is 20000, population is 80, cross over rate 0.5 and mutation rate is 1. The others ordering policies for some other combinations are shown in Appendix C.

6.2.2.3 Graphical presentation of analysis 2

The above ordering quantities are plotted in the following figure 6.2

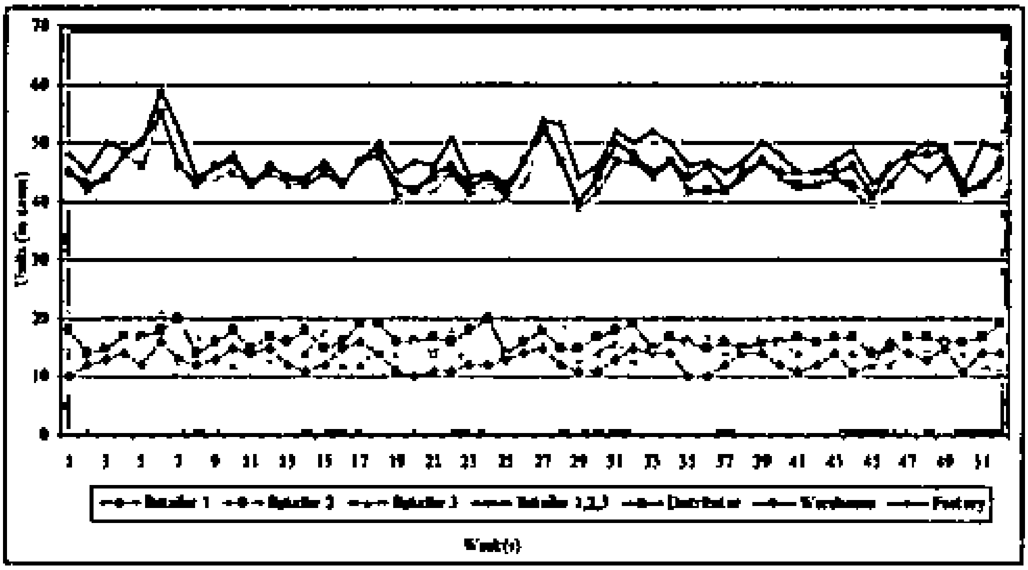

Figure 6.2: Graphical presentation of ordering policy for analysis 2

6.3 COMPARISONS BETWEEN RESULTS BEFORE AND AFTER GA

Comparisons between the results obtained by genetic algorithm for both the analyses and from the results of simulation of the existing system are shown in this section.

In order to find out which is the best ordering policy, a detail comparison has been conducted between the existing ordering policy and the ordering policy obtained from genetic algorithm from analysis 1 and analysis 2.

6.3.1 Comparison on the basis of cost

The main basis of comparison is the total supply chain cost (TSCC). The costs of one year of the existing system considering all the costs of holding, ordering, back order, distribution, and production are shown in the following table 6.7. A detail calculation of ordering policy and costs are shown on appendix A.

Table 6.7: Ordering policy for the existing system along with the total supply chain cost

Week	Retailer 1 (units)	Retailer 2(units)	Retailer 3(units)	Retailer 1,2,3(total)(units)	Distributor(units)	Warehouse(units)	Factory(units)	Total Supply chain Cost Tk.
1	10	24	24	58	101	212	424	124329.6
2	12	11	15	38	18	0	0	9567.5
3	15	16	14	45	52	10	0	12993.25
4	15	17	17	49	53	54	0	22222.95
5	8	18	18	44	39	25	0	15553
6	19	19	25	63	82	125	15	41233.25
7	9	20	5	34	5	0	0	8472
8	8	9	21	38	42	7	0	10643.6
9	16	18	13	47	56	70	22	28197.75
10	17	18	7	42	37	18	0	13582.4
11	11	13	13	37	32	27	2	14533.35
12	17	13	14	44	51	70	113	41986.5
13	5	18	17	40	36	21	0	13694.3
14	12	18	11	41	42	48	47	26607.65
15	13	11	21	45	49	56	64	31746.55
16	16	16	7	39	33	17	0	12698.35
17	16	23	10	49	59	85	131	48851.25
18	9	17	19	45	41	23	0	15224.65
19	10	12	13	35	25	9	0	10286.95
20	9	17	18	44	53	81	109	43453.8
21	12	18	12	42	40	27	0	15293.6

22	9	15	20	44	46	52	50	28530.6
23	12	20	5	37	30	14	0	11673.45
24	13	22	9	44	51	72	106	41256.1
25	14	8	18	40	36	21	0	13696.3
26	15	18	12	45	50	64	77	35343.45
27	16	18	23	57	69	88	112	48219.15
28	9	13	20	42	27	0	0	10181
29	10	13	7	30	18	0	0	7445.5
30	9	20	11	40	50	76	64	34432.8
31	14	19	18	51	62	74	72	37816.95
32	14	20	11	45	39	16	0	13889.55
33	15	11	17	43	41	43	28	23089.15
34	12	13	17	42	41	41	39	24227.3
35	7	18	12	37	32	23	5	14245.15
36	10	14	20	44	51	70	117	42622.5
37	14	17	9	40	36	21	0	13694.3
38	16	14	17	47	54	72	95	40188.35
39	12	15	17	44	41	28	0	15929.9
40	11	17	16	44	44	47	50	27577.1
41	10	18	10	38	32	20	0	13031.5
42	13	13	17	43	48	64	101	38705.95
43	16	17	11	44	45	42	20	21848.1
44	8	18	15	41	38	31	20	19066.55
45	13	11	12	36	31	24	17	16116.7
46	18	16	11	45	54	77	130	46253.35
47	9	17	20	46	47	40	3	19216
48	14	18	12	44	42	37	34	23121.1
49	15	15	16	46	48	54	71	32707.7
50	6	16	13	35	24	0	0	8537.75
51	14	18	10	42	49	74	94	39277.2
52	14	13	10	37	32	15	0	11881.75
						Total supply chain cost (Tk.) =		13,34,995

The ordering quantities and costs calculated from genetic algorithm of analysis I for one year is shown in table 6.3. Now from table 6.7 and from table 6.3, it is clearly visible that the total supply chain cost reduces from Tk. 13,34,995 to Tk.6,60,109.8 after applying genetic algorithm, which is a reduction of Tk.6,74,285.2. This reduced amount is almost 50.5% of the existing cost. So, the value of total cost of supply chain evidently shows that genetic algorithm has the ability to reduce total supply chain cost as well as the bullwhip effect.

In analysis 2 the best optimal ordering quantity has total supply chain cost of Tk.4,03.981.15 shown in table 6.6. It has the supply chain cost less than Tk. 9.31,013.85 from the existing ordering policy. This reduced amount is almost 69.74% of the existing supply chain cost. Table 6.8 summarizes the difference between costs of total supply chain before and after applying genetic algorithm.

Table 6.8: Total Supply chain costs before and after applying genetic algorithm

	Existing System	Analysis 1	Analysis 2
Total Supply Chain Cost (Tk.)	13,34,995	6,60,109.8	4,03,981.15

So, both the analysis shows that genetic algorithm is capable of reducing total supply chain cost and thus the bullwhip effect is also reduced.

6.3.2 Comparison on the basis of variability of ordering quantity

Table 6.7 shows the ordering pattern for all the six members of the supply chain before applying genetic algorithm. The variability in the ordering pattern in each member is distinctively visible in this case. Again in table 6.3 the order pattern is displayed after the use of genetic algorithm of analysis 1 and in table 6.6 the order pattern is shown from analysis 2. Now, in order to find the differences between variability in order pattern in for all the cases table 6.9 shows the highest and the lowest order quantities for each member of the supply chain before and after applying genetic algorithm

Table 6.9: Highest and Lowest ordering quantity before and after Genetic Algorithm

		Retailer 1	Retailer 2	Retailer 3	Distributor	Ware house	Factory
Before Applying Genetic Algorithm	Highest Order quantity	19	24	25	101	212	424
	Lowest order quantity	6	8	5	18	0	0
After applying Genetic Algorithm in analysis 1	Highest Order quantity	21	23	24	60	66	83
	Lowest order quantity	10	14	11	41	48	50
After applying Genetic Algorithm in analysis 2	Highest Order quantity	16	20	21	55	55	59
	Lowest order quantity	10	14	11	39	41	43

Though the demand of customers, beginning inventory, lead time, ordering cycle are same for both the cases of before and after applying genetic algorithm, the variability of ordering pattern is more in the supply chain members before using genetic algorithm. In this case the variability increases in the up streams of the supply chain network and the highest variability is in the last member of the supply chain which is factory.

However, in the ordering policy after genetic algorithm, the ordering quantity variation decreases largely than the ordering policy found before applying genetic algorithm shown in table 6.9.

Thus after applying genetic algorithm the ordering patterns for each week are much more stable than the ordering pattern of the existing case, which actually implies the reduction of bullwhip effect.

6.4 COMPARISON BETWEEN ANALYSIS 1 AND ANALYSIS 2

In order to find the best optimal ordering quantities for each of the six members of the supply chain genetic algorithm is used with various combinations. In analysis 1 chromosomes vary from 0 to 25 and in analysis 2 chromosomes vary from 0 to 10. In both the case the total supply chain cost is reduced than the existing ordering policy. However, in analysis 2 the total supply chain cost is lower than the result of analysis 1. Again in analysis 2 the variability of demand is also reduced more than the results of analysis 1. This difference is distinctively visible in figure 6.1 and in figure 6.2.

This research shows that with a lower limit of chromosomes, genetic algorithm is capable to reduce the total supply chain cost more and thus to mitigate the bullwhip effect largely.

This research also shows that variation of the value of limit to the chromosomes has a great impact on the reduction of bullwhip effect.

6.5 CONCLUSION

The results of the above analyses show that genetic algorithm is capable of reducing total supply chain cost as well as bullwhip effect from a complicated supply chain network. These analyses also show that limit set to the chromosomes is important in order to reduce the bullwhip even more. Lower range chromosomes provide a better result than the range set in higher limit.

CHAPTER 7
CONCLUSIONS AND RECOMENDATIONS

7.1 CONCLUSIONS

This research has used genetic algorithm as a technique to find the optimal ordering quantities for the members of a real supply chain. The objective function used here for genetic algorithm is to minimize the total supply chain cost. Genetic algorithm searched extensively for the global optima where the costs would be the lowest for the total supply chain. In the objective function maximum five types of costs are considered. Costs of each member are considered separately. In order to find out the total costs, all the relevant amount of costs like holding cost, back order cost , distribution cost, production cost data are provided.

Since bullwhip effect occurs for the order amplifications which implies to the wrong ordering quantities of the members of supply chain. To reduce that an approach is taken where the chromosomes of genetic algorithm of this research represent the extra demand themselves.

Though there have been many researches to find the techniques to reduce the bullwhip effect, this research distinctively shows that genetic algorithm has the ability to reduce the bullwhip effect by finding the optimal ordering quantities for the supply chain members on the basis of minimizing total supply chain cost.

In past, none of the researchers used genetic algorithm to find the optimum ordering policy that will reduce bullwhip in a real supply chain; neither had they used a complex supply chain model having more than one retailer in their study. This research has involved a more complex supply chain network containing three retailers in a supply chain with a total of six members.

The cost functions used in the research requires different cost data. All the data used in this research are different for each member of the supply chain. They vary relevantly from one member to each member. None of the researches before used varying cost data which also makes this research unique and different.

However, this research must also admit the limitations. In order to mitigate the bullwhip effect in a real supply chain all the data are collected from real supply chain to mitigate the bullwhip effect. These collected data relied mostly on the management of each members of the supply chain. To find a more accurate optimum ordering policy precise data providing as input is a must.

7.2 RECOMMENDATIONS

To find out the optimal ordering quantity which will reduce bullwhip, a number of cost functions are used to minimize the cost of total supply chain. In future some other cost criteria can be included to make the costs more appropriate.

In this research though the considered costs are different for each member, but for a particular member they are constant. Future research can be carried out by varying the costs for each member on the basis of time or quantity.

In this research mainly two different sets of analyses are conducted by varying the chromosomes from 0-25 and from 0-10. Limiting chromosomes have provided very different results. In future further, researches can be conducted by varying the chromosomes in different other ranges

In this research single point crossover and roulettewheel mechanism for selection have been used. Some other crossover points like two point cross over, multipoint crossover and some other selection processes can be used to see the results.

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Appendix A

Ordering quantity of the retailers for the existing case for year 1 and 2

	Retailer 1							Retailer 2							Retailer 3						
week	Beginning inventory	Demand	Ending inventory	Shortage Quantity	adjusted stock	Order quantity	Max order	Beginning inventory	Demand	Ending inventory	Shortage Quantity	adjusted stock	Order quantity	Max order	Beginning inventory	Demand	Ending inventory	Shortage Quantity	adjusted stock	Order quantity	Max order
1	20	10	10	0	0	10	10	20	17	3	0	7	24	24	20	17	3	0	7	24	24
2	20	11	9	0	1	12	12	27	14	13	0	-3	11	11	27	16	11	0	-1	15	15
3	21	13	8	0	2	15	15	24	15	9	0	1	16	16	26	15	11	0	-1	14	14
4	23	14	9	0	1	15	15	25	16	9	0	1	17	17	25	16	9	0	1	17	17
5	24	11	13	0	-3	8	8	26	17	9	0	1	18	18	26	17	9	0	1	18	18
6	21	15	6	0	4	19	19	27	18	9	0	1	19	19	27	21	6	0	4	25	25
7	25	12	13	0	-3	9	9	28	19	9	0	1	20	20	31	13	18	0	-8	5	5
8	22	10	12	0	-2	8	8	29	14	15	0	-5	9	9	23	17	6	0	4	21	21
9	20	13	7	0	3	16	16	24	16	8	0	2	18	18	27	15	12	0	-2	13	13
10	23	15	8	0	2	17	17	26	17	9	0	1	18	18	25	11	14	0	-4	7	7
11	25	13	12	0	-2	11	11	27	15	12	0	-2	13	13	21	12	9	0	1	13	13
12	23	15	8	0	2	17	17	25	14	11	0	-1	13	13	22	13	9	0	1	14	14
13	25	10	15	0	-5	5	5	24	16	8	0	2	18	18	23	15	8	0	2	17	17
14	20	11	9	0	1	12	12	26	17	9	0	1	18	18	25	13	12	0	-2	11	11
15	21	12	9	0	1	13	13	27	14	13	0	-3	11	11	23	17	6	0	4	21	21
16	22	14	8	0	2	16	16	24	15	9	0	1	16	16	27	12	15	0	-5	7	7
17	24	15	9	0	1	16	16	25	19	6	0	4	23	23	22	11	11	0	-1	10	10
18	25	12	13	0	-3	9	9	29	18	11	0	-1	17	17	21	15	6	0	4	19	19
19	22	11	11	0	-1	10	10	28	15	13	0	-3	12	12	25	14	11	0	-1	13	13
20	21	10	11	0	-1	9	9	25	16	9	0	1	17	17	24	16	8	0	2	18	18
21	20	11	9	0	1	12	12	26	17	9	0	1	18	18	26	14	12	0	-2	12	12
22	21	10	11	0	-1	9	9	27	16	11	0	-1	15	15	24	17	7	0	3	20	20
23	20	11	9	0	1	12	12	26	18	8	0	2	20	20	27	11	16	0	-6	5	5
24	21	12	9	0	1	13	13	28	20	8	0	2	22	22	21	10	11	0	-1	9	9
25	22	13	9	0	1	14	14	30	14	16	0	-6	8	8	20	14	6	0	4	18	18
26	23	14	9	0	1	15	15	24	16	8	0	2	18	18	24	13	11	0	-1	12	12
27	24	15	9	0	1	16	16	26	17	9	0	1	18	18	23	18	5	0	5	23	23
28	25	12	13	0	-3	9	9	27	15	12	0	-2	13	13	28	19	9	0	1	20	20

29	22	11	11	0	-1	10	10	25	14	11	0	-1	13	13	29	13	16	0	-6	7	7
30	21	10	11	0	-1	9	9	24	17	7	0	3	20	20	23	12	11	0	-1	11	11
31	20	12	8	0	2	14	14	27	18	9	0	1	19	19	22	15	7	0	3	18	18
32	22	13	9	0	1	14	14	28	19	9	0	1	20	20	25	13	12	0	-2	11	11
33	23	14	9	0	1	15	15	29	15	14	0	-4	11	11	23	15	8	0	2	17	17
34	24	13	11	0	-1	12	12	25	14	11	0	-1	13	13	25	16	9	0	1	17	17
35	23	10	13	0	-3	7	7	24	16	8	0	2	18	18	26	14	12	0	-2	12	12
36	20	10	10	0	0	10	10	26	15	11	0	-1	14	14	24	17	7	0	3	20	20
37	20	12	8	0	2	14	14	25	16	9	0	1	17	17	27	13	14	0	-4	9	9
38	22	14	8	0	2	16	16	26	15	11	0	-1	14	14	23	15	8	0	2	17	17
39	24	13	11	0	-1	12	12	25	15	10	0	0	15	15	25	16	9	0	1	17	17
40	23	12	11	0	-1	11	11	25	16	9	0	1	17	17	26	16	10	0	0	16	16
41	22	11	11	0	-1	10	10	26	17	9	0	1	18	18	26	13	13	0	-3	10	10
42	21	12	9	0	1	13	13	27	15	12	0	-2	13	13	23	15	8	0	2	17	17
43	22	14	8	0	2	16	16	25	16	9	0	1	17	17	25	13	12	0	-2	11	11
44	24	11	13	0	-3	8	8	26	17	9	0	1	18	18	23	14	9	0	1	15	15
45	21	12	9	0	1	13	13	27	14	13	0	-3	11	11	24	13	11	0	-1	12	12
46	22	15	7	0	3	18	18	24	15	9	0	1	16	16	23	12	11	0	-1	11	11
47	25	12	13	0	-3	9	9	25	16	9	0	1	17	17	22	16	6	0	4	20	20
48	22	13	9	0	1	14	14	26	17	9	0	1	18	18	26	14	12	0	-2	12	12
49	23	14	9	0	1	15	15	27	16	11	0	-1	15	15	24	15	9	0	1	16	16
50	24	10	14	0	-4	6	6	26	16	10	0	0	16	16	25	14	11	0	-1	13	13
51	20	12	8	0	2	14	14	26	17	9	0	1	18	18	24	12	12	0	-2	10	10
52	22	13	9	0	1	14	14	27	15	12	0	-2	13	13	22	11	11	0	-1	10	10
53	23	10	13	0	-3	7	7	25	17	8	0	2	19	19	21	17	4	0	6	23	23
54	20	11	9	0	1	12	12	27	14	13	0	-3	11	11	27	16	11	0	-1	15	15
55	21	13	8	0	2	15	15	24	15	9	0	1	16	16	26	15	11	0	-1	14	14
56	23	14	9	0	1	15	15	25	16	9	0	1	17	17	25	16	9	0	1	17	17
57	24	11	13	0	-3	8	8	26	17	9	0	1	18	18	26	17	9	0	1	18	18
58	21	15	6	0	4	19	19	27	18	9	0	1	19	19	27	21	6	0	4	25	25
59	25	12	13	0	-3	9	9	28	19	9	0	1	20	20	31	13	18	0	-8	5	5
60	22	10	12	0	-2	8	8	29	14	15	0	-5	9	9	23	17	6	0	4	21	21
61	20	13	7	0	3	16	16	24	16	8	0	2	18	18	27	15	12	0	-2	13	13
62	23	15	8	0	2	17	17	26	17	9	0	1	18	18	25	11	14	0	-4	7	7
63	25	13	12	0	-2	11	11	27	15	12	0	-2	13	13	21	12	9	0	1	13	13
64	23	15	8	0	2	17	17	25	14	11	0	-1	13	13	22	13	9	0	1	14	14
65	25	10	15	0	-5	5	5	24	16	8	0	2	18	18	23	15	8	0	2	17	17
66	20	11	9	0	1	12	12	26	17	9	0	1	18	18	25	13	12	0	-2	11	11
67	21	12	9	0	1	13	13	27	14	13	0	-3	11	11	23	17	6	0	4	21	21
3	22	14	8	0	2	16	16	24	15	9	0	1	16	16	27	12	15	0	-5	7	7
69	24	15	9	0	1	16	16	25	19	6	0	4	23	23	22	11	11	0	-1	10	10

70	25	12	13	0	-3	9	9	29	18	11	0	-1	17	17	21	15	6	0	4	19	19
71	22	11	11	0	-1	10	10	28	15	13	0	-3	12	12	25	14	11	0	-1	13	13
72	21	10	11	0	-1	9	9	25	16	9	0	1	17	17	24	16	8	0	2	18	18
73	20	11	9	0	1	12	12	26	17	9	0	1	18	18	26	14	12	0	-2	12	12
74	21	10	11	0	-1	9	9	27	16	11	0	-1	15	15	24	17	7	0	3	20	20
75	20	11	9	0	1	12	12	26	18	8	0	2	20	20	27	11	16	0	-6	5	5
76	21	12	9	0	1	13	13	28	20	8	0	2	22	22	21	10	11	0	-1	9	9
77	22	13	9	0	1	14	14	30	14	16	0	-6	8	8	20	14	6	0	4	18	18
78	23	14	9	0	1	15	15	24	16	8	0	2	18	18	24	13	11	0	-1	12	12
79	24	15	9	0	1	16	16	26	17	9	0	1	18	18	23	18	5	0	5	23	23
80	25	12	13	0	-3	9	9	27	15	12	0	-2	13	13	28	19	9	0	1	20	20
81	22	11	11	0	-1	10	10	25	14	11	0	-1	13	13	29	13	16	0	-6	7	7
82	21	10	11	0	-1	9	9	24	17	7	0	3	20	20	23	12	11	0	-1	11	11
83	20	12	8	0	2	14	14	27	18	9	0	1	19	19	22	15	7	0	3	18	18
84	22	13	9	0	1	14	14	28	19	9	0	1	20	20	25	13	12	0	-2	11	11
85	23	14	9	0	1	15	15	29	15	14	0	-4	11	11	23	15	8	0	2	17	17
86	24	13	11	0	-1	12	12	25	14	11	0	-1	13	13	25	16	9	0	1	17	17
87	23	10	13	0	-3	7	7	24	16	8	0	2	18	18	26	14	12	0	-2	12	12
88	20	10	10	0	0	10	10	26	15	11	0	-1	14	14	24	17	7	0	3	20	20
89	20	12	8	0	2	14	14	25	16	9	0	1	17	17	27	13	14	0	-4	9	9
90	22	14	8	0	2	16	16	26	15	11	0	-1	14	14	23	15	8	0	2	17	17
91	24	13	11	0	-1	12	12	25	15	10	0	0	15	15	25	16	9	0	1	17	17
92	23	12	11	0	-1	11	11	25	16	9	0	1	17	17	26	16	10	0	0	16	16
93	22	11	11	0	-1	10	10	26	17	9	0	1	18	18	26	13	13	0	-3	10	10
94	21	12	9	0	1	13	13	27	15	12	0	-2	13	13	23	15	8	0	2	17	17
95	22	14	8	0	2	16	16	25	16	9	0	1	17	17	25	13	12	0	-2	11	11
96	24	11	13	0	-3	8	8	26	17	9	0	1	18	18	23	14	9	0	1	15	15
97	21	12	9	0	1	13	13	27	14	13	0	-3	11	11	24	13	11	0	-1	12	12
98	22	15	7	0	3	18	18	24	15	9	0	1	16	16	23	12	11	0	-1	11	11
99	25	12	13	0	-3	9	9	25	16	9	0	1	17	17	22	16	6	0	4	20	20
100	22	13	9	0	1	14	14	26	17	9	0	1	18	18	26	14	12	0	-2	12	12
101	23	14	9	0	1	15	15	27	16	11	0	-1	15	15	24	15	9	0	1	16	16
102	24	10	14	0	-4	6	6	26	16	10	0	0	16	16	25	14	11	0	-1	13	13
103	20	12	8	0	2	14	14	26	17	9	0	1	18	18	24	12	12	0	-2	10	10
104	22	13	9	0	1	14	14	27	15	12	0	-2	13	13	22	11	11	0	-1	10	10

Existing case ordering quantity for distributor, warehouse and factory for year 1 and year 2

	Distributor							Warehouse							Factory						
week	Beginning inventory	Demand	Ending inventory	Shortage Quantity	Adjusted stock	Order quantity	Max order	Beginning inventory	Demand	Ending inventory	Shortage Quantity	Adjusted stock	Order quantity	Max order	Beginning inventory	Demand	Ending inventory	Shortage Quantity	Adjusted stock	Order quantity	Max order
1	75	58	17	0	43	101	101	90	101	0	11	100	212	212	100	212	0	112	100	424	424
2	118	38	80	0	-20	18	18	212	18	194	0	-94	-76	0	424	0	424	0	-324	-324	0
3	98	45	53	0	7	52	52	194	52	142	0	-42	10	10	424	10	414	0	-314	-304	0
4	105	49	56	0	4	53	53	152	53	99	0	1	54	54	414	54	360	0	-260	-206	0
5	109	44	65	0	-5	39	39	153	39	114	0	-14	25	25	360	25	335	0	-235	-210	0
6	104	63	41	0	19	82	82	139	82	57	0	43	125	125	335	125	210	0	-110	15	15
7	123	34	89	0	-29	5	5	182	5	177	0	-77	-72	0	225	0	225	0	-125	-125	0
8	94	38	56	0	4	42	42	177	42	135	0	-35	7	7	225	7	218	0	-118	-111	0
9	98	47	51	0	9	56	56	142	56	86	0	14	70	70	218	70	148	0	-48	22	22
10	107	42	65	0	-5	37	37	156	37	119	0	-19	18	18	170	18	152	0	-52	-34	0
11	102	37	65	0	-5	32	32	137	32	105	0	-5	27	27	152	27	125	0	-25	2	2
12	97	44	53	0	7	51	51	132	51	81	0	19	70	70	127	70	57	0	43	113	113
13	104	40	64	0	-4	36	36	151	36	115	0	-15	21	21	170	21	149	0	-49	-28	0
14	100	41	59	0	1	42	42	136	42	94	0	6	48	48	149	48	101	0	-1	47	47
15	101	45	56	0	4	49	49	142	49	93	0	7	56	56	148	56	92	0	8	64	64
16	105	39	66	0	-6	33	33	149	33	116	0	-16	17	17	156	17	139	0	-39	-22	0
17	99	49	50	0	10	59	59	133	59	74	0	26	85	85	139	85	54	0	46	131	131
18	109	45	64	0	-4	41	41	159	41	118	0	-18	23	23	185	23	162	0	-62	-39	0
19	105	35	70	0	-10	25	25	141	25	116	0	-16	9	9	162	9	153	0	-53	-44	0
20	95	41	51	0	9	53	53	125	53	72	0	28	81	81	153	81	72	0	28	109	109
21	104	42	62	0	-2	40	40	153	40	113	0	-13	27	27	181	27	154	0	-54	-27	0
22	102	44	58	0	2	46	46	140	46	94	0	6	52	52	154	52	102	0	-2	50	50
23	104	37	67	0	-7	30	30	146	30	116	0	-16	14	14	152	14	138	0	-38	-24	0
24	97	44	53	0	7	51	51	130	51	79	0	21	72	72	138	72	66	0	34	106	106
25	104	40	64	0	-4	36	36	151	36	115	0	-15	21	21	172	21	151	0	-51	-30	0
26	100	45	55	0	5	50	50	136	50	86	0	14	64	64	151	64	87	0	13	77	77
27	105	57	48	0	12	69	69	150	69	81	0	19	88	88	164	88	76	0	24	112	112
28	117	42	75	0	-15	27	27	169	27	142	0	-42	-15	0	188	0	188	0	-88	-88	0
29	102	30	72	0	-12	18	18	142	18	124	0	-24	-6	0	188	0	188	0	-88	-88	0

30	90	40	50	0	10	50	50	124	50	74	0	26	76	76	188	76	112	0	-12	64	64
31	100	51	49	0	11	62	62	150	62	88	0	12	74	74	176	74	102	0	-2	72	72
32	111	45	66	0	-6	39	39	162	39	123	0	-23	16	16	174	16	158	0	-58	-42	0
33	105	43	62	0	-2	41	41	139	41	98	0	2	43	43	158	43	115	0	-15	28	28
34	103	42	61	0	-1	41	41	141	41	100	0	0	41	41	143	41	102	0	-2	39	39
35	102	37	65	0	-5	32	32	141	32	109	0	-9	23	23	141	23	118	0	-18	5	5
36	97	44	53	0	7	51	51	132	51	81	0	19	70	70	123	70	53	0	47	117	117
37	101	40	64	0	-4	36	36	151	36	115	0	-15	21	21	170	21	149	0	-49	-28	0
38	100	47	53	0	7	54	54	136	54	82	0	18	72	72	149	72	77	0	23	95	95
39	107	44	63	0	-3	41	41	154	41	113	0	-13	28	28	172	28	144	0	-44	-16	0
40	104	44	60	0	0	44	44	141	44	97	0	3	47	47	144	47	97	0	3	50	50
41	104	38	66	0	-6	32	32	144	32	112	0	-12	20	20	147	20	127	0	-27	-7	0
42	98	43	55	0	5	48	48	132	48	84	0	16	64	64	127	64	63	0	37	101	101
43	103	44	59	0	1	45	45	148	45	103	0	-3	42	42	164	42	122	0	-22	20	20
44	104	41	63	0	-3	38	38	145	38	107	0	-7	31	31	142	31	111	0	-11	20	20
45	101	36	65	0	-5	31	31	138	31	107	0	-7	24	24	131	24	107	0	-7	17	17
46	96	45	51	0	9	54	54	131	54	77	0	23	77	77	124	77	47	0	53	130	130
47	105	46	59	0	1	47	47	154	47	107	0	-7	40	40	177	40	137	0	-37	3	3
48	106	44	62	0	-2	42	42	147	42	105	0	-5	37	37	140	37	103	0	-3	34	34
49	104	46	58	0	2	48	48	142	48	94	0	6	54	54	137	54	83	0	17	71	71
50	106	35	71	0	-11	24	24	148	24	124	0	-24	0	0	154	0	154	0	-54	-54	0
51	95	42	53	0	7	49	49	124	49	75	0	25	74	74	154	74	80	0	20	94	94
52	102	37	65	0	-5	32	32	149	32	117	0	-17	15	15	174	15	159	0	-59	-44	0
53	97	49	48	0	12	61	61	132	61	71	0	29	90	90	159	90	69	0	31	121	121
54	109	38	71	0	-11	27	27	161	27	134	0	-34	-7	0	190	0	190	0	-90	-90	0
55	98	45	53	0	7	52	52	134	52	82	0	18	70	70	190	70	120	0	-20	50	50
56	105	49	56	0	4	53	53	152	53	99	0	1	54	54	170	54	116	0	-16	38	38
57	109	44	65	0	-5	39	39	153	39	114	0	-14	25	25	154	25	129	0	-29	-4	0
58	104	63	41	0	19	82	82	139	82	57	0	43	125	125	129	125	4	0	96	221	221
59	123	34	89	0	-29	5	5	182	5	177	0	-77	-72	0	225	0	225	0	-125	-125	0
60	94	38	56	0	4	42	42	177	42	135	0	-35	7	7	225	7	218	0	-118	-111	0
61	98	47	51	0	9	56	56	142	56	86	0	14	70	70	218	70	148	0	-48	22	22
62	107	42	65	0	-5	37	37	156	37	119	0	-19	18	18	170	18	152	0	-52	-34	0
63	102	37	65	0	-5	32	32	137	32	105	0	-5	27	27	152	27	125	0	-25	2	2
64	97	44	53	0	7	51	51	132	51	81	0	19	70	70	127	70	57	0	43	113	113
65	104	40	64	0	-4	36	36	151	36	115	0	-15	21	21	170	21	149	0	-49	-28	0
66	100	41	59	0	1	42	42	136	42	94	0	6	48	48	149	48	101	0	-1	47	47
67	101	45	56	0	4	49	49	142	49	93	0	7	56	56	148	56	92	0	8	64	64
3	105	39	66	0	-6	33	33	149	33	116	0	-16	17	17	156	17	139	0	-39	-22	0
69	99	49	50	0	10	59	59	133	59	74	0	26	85	85	139	85	54	0	46	131	131

70	109	45	64	0	-4	41	41	159	41	118	0	-18	23	23	185	23	162	0	-62	-39	0
71	105	35	70	0	-10	25	25	141	25	116	0	-16	9	9	162	9	153	0	-53	-44	0
72	95	44	51	0	9	53	53	125	53	72	0	28	81	81	153	81	72	0	28	109	109
73	101	42	62	0	-2	40	40	153	40	113	0	-13	27	27	181	27	154	0	-54	-27	0
74	102	44	58	0	2	46	46	140	46	94	0	6	52	52	154	52	102	0	-2	50	50
75	104	37	67	0	-7	30	30	146	30	116	0	-16	14	14	152	14	138	0	-38	-24	0
76	97	44	53	0	7	51	51	130	51	79	0	21	72	72	138	72	66	0	34	106	106
77	104	40	64	0	-4	36	36	151	36	115	0	-15	21	21	172	21	151	0	-51	-30	0
78	100	45	55	0	5	50	50	136	50	86	0	14	64	64	151	64	87	0	13	77	77
79	105	57	48	0	12	69	69	150	69	81	0	19	88	88	164	88	76	0	24	112	112
80	117	42	75	0	-15	27	27	169	27	142	0	-42	-15	0	188	0	188	0	-88	-88	0
81	102	30	72	0	-12	18	18	142	18	124	0	-21	-6	0	188	0	188	0	-88	-88	0
82	90	40	50	0	10	50	50	124	50	74	0	26	76	76	188	76	112	0	-12	64	64
83	100	51	49	0	11	62	62	150	62	88	0	12	74	74	176	74	102	0	-2	72	72
84	111	45	66	0	-6	39	39	162	39	123	0	-23	16	16	174	16	158	0	-58	-42	0
85	105	43	62	0	-2	41	41	139	41	98	0	2	43	43	158	43	115	0	-15	28	28
86	103	42	61	0	-1	41	41	141	41	100	0	0	41	41	143	41	102	0	-2	39	39
87	102	37	65	0	-5	32	32	141	32	109	0	-9	23	23	141	23	118	0	-18	5	5
88	97	44	53	0	7	51	51	132	51	81	0	19	70	70	123	70	53	0	47	117	117
89	104	40	64	0	-4	36	36	151	36	115	0	-15	21	21	170	21	149	0	-49	-28	0
90	100	47	53	0	7	51	54	136	54	82	0	18	72	72	149	72	77	0	23	95	95
91	107	44	63	0	-3	41	41	154	41	113	0	-13	28	28	172	28	144	0	-44	-16	0
92	104	44	60	0	0	44	44	141	44	97	0	3	47	47	144	47	97	0	3	50	50
93	104	38	66	0	-6	32	32	144	32	112	0	-12	20	20	147	20	127	0	-27	-7	0
94	98	43	55	0	5	48	48	132	48	84	0	16	64	64	127	64	63	0	37	101	101
95	103	44	59	0	1	45	45	148	45	103	0	-3	42	42	164	42	122	0	-22	20	20
96	104	41	63	0	-3	38	38	145	38	107	0	-7	31	31	142	31	111	0	-11	20	20
97	101	36	65	0	-5	31	31	138	31	107	0	-7	24	24	131	24	107	0	-7	17	17
98	96	45	51	0	9	54	54	131	54	77	0	23	77	77	124	77	47	0	53	130	130
99	105	46	59	0	1	47	47	154	47	107	0	-7	40	40	177	40	137	0	-37	3	3
100	106	44	62	0	-2	42	42	147	42	105	0	-5	37	37	140	37	103	0	-3	34	34
101	104	46	58	0	2	48	48	142	48	94	0	6	54	54	137	54	83	0	17	71	71
102	106	35	71	0	-11	24	24	148	24	124	0	-24	0	0	154	0	154	0	-54	-54	0
103	95	42	53	0	7	49	49	124	49	75	0	25	74	74	154	74	80	0	20	94	94
104	102	37	65	0	-5	32	32	149	32	117	0	-17	15	15	174	15	159	0	-59	-44	0

Detail Cost Calculation for Each Member of the Supply Chain for the Existing Situation

	Retailer 1			Retailer 2			Retailer 3			Distributor				Warehouse				Factory					
Week	Inventory Cost	Backorder Cost	Ordering Cost	Inventory Cost	Backorder Cost	Ordering Cost	Inventory Cost	Backorder Cost	Ordering Cost	Inventory Cost	Backorder Cost	Ordering Cost	Distribution Cost	Inventory Cost	Backorder Cost	Ordering Cost	Distribution Cost	Inventory Cost	Backorder Cost	Ordering Cost	Distribution Cost	Production Cost	TSCC
1	20	0	35	6	0	37	6	0	40	25.5	0	35	13152	0	220	0	20705	0	2240	80	40556	67840	124329.6
2	18	0	35	26	0	37	22	0	40	120	0	35	8617	194	0	0	3690	424	0	0	0	0	9567.5
3	16	0	35	18	0	37	22	0	40	79.5	0	35	10204	142	0	0	10660	414	0	0	1913	0	12993.25
4	18	0	35	18	0	37	18	0	40	84	0	35	11111	99	0	0	10865	360	0	0	10330	0	22222.95
5	26	0	35	18	0	37	18	0	40	97.5	0	35	9977	114	0	0	7995	335	0	0	4783	0	15553
6	12	0	35	18	0	37	12	0	40	61.5	0	35	14285	57	0	0	16810	210	0	80	23913	2700	41233.25
7	26	0	35	18	0	37	36	0	40	133.5	0	35	7710	177	0	0	1025	225	0	0	0	0	8472
8	24	0	35	30	0	37	12	0	40	84	0	35	8617	135	0	0	8610	218	0	0	1339	0	10643.6
9	14	0	35	16	0	37	24	0	40	76.5	0	35	10657	86	0	0	11480	148	0	80	13391	3960	28197.75
10	16	0	35	18	0	37	28	0	40	97.5	0	35	9524	119	0	0	7585	152	0	0	3443	0	13582.4
11	24	0	35	24	0	37	18	0	40	97.5	0	35	8390	105	0	0	6560	125	0	80	5165	360	14533.35
12	16	0	35	22	0	37	18	0	40	79.5	0	35	9977	81	0	0	10455	57	0	80	13391	20340	41986.5
13	30	0	35	16	0	37	16	0	40	96	0	35	9070	115	0	0	7380	149	0	0	4017	0	13694.3
14	18	0	35	18	0	37	24	0	40	88.5	0	35	9297	94	0	0	8610	101	0	80	9182	8460	26607.65
15	18	0	35	26	0	37	12	0	40	84	0	35	10204	93	0	0	10045	92	0	80	10713	11520	31746.55
16	16	0	35	18	0	37	30	0	40	99	0	35	8843	116	0	0	6765	139	0	0	3252	0	12698.35
17	18	0	35	12	0	37	22	0	40	75	0	35	11111	74	0	0	12095	54	0	80	16261	23580	48851.25
18	26	0	35	22	0	37	12	0	40	96	0	35	10204	118	0	0	8405	162	0	0	4400	0	15224.65
19	22	0	35	26	0	37	22	0	40	105	0	35	7936	116	0	0	5125	153	0	0	1722	0	10286.95
20	22	0	35	18	0	37	16	0	40	76.5	0	35	9977	72	0	0	10865	72	0	80	15495	19620	43453.8
21	18	0	35	18	0	37	24	0	40	93	0	35	9524	113	0	0	8200	154	0	0	5165	0	15293.6
22	22	0	35	22	0	37	14	0	40	87	0	35	9977	94	0	0	9430	102	0	80	9948	9000	28530.6
23	18	0	35	16	0	37	32	0	40	100.5	0	35	8390	116	0	0	6150	138	0	0	2678	0	11673.45

24	18	0	35	16	0	37	22	0	40	79.5	0	35	9977	79	0	0	10455	66	0	80	13774	19080	41256.1
25	18	0	35	32	0	37	12	0	40	96	0	35	9070	115	0	0	7380	151	0	0	4017	0	13696.3
26	18	0	35	16	0	37	22	0	40	82.5	0	35	10204	86	0	0	10250	87	0	80	12243	13860	35343.45
27	18	0	35	18	0	37	10	0	40	72	0	35	12925	81	0	0	14145	76	0	80	16834	20160	48219 15
28	26	0	35	24	0	37	18	0	40	112.5	0	35	9524	142	0	0	5535	188	0	0	0	0	10181
29	22	0	35	22	0	37	32	0	40	108	0	35	6803	124	0	0	3690	188	0	0	0	0	7445 5
30	22	0	35	14	0	37	22	0	40	75	0	35	9070	74	0	0	10250	112	0	80	14539	11520	34432.8
31	16	0	35	18	0	37	14	0	40	73.5	0	35	11564	88	0	0	12710	102	0	80	14156	12960	37816.95
32	18	0	35	18	0	37	24	0	40	99	0	35	10204	123	0	0	7995	158	0	0	3061	0	13889.55
33	18	0	35	28	0	37	16	0	40	93	0	35	9750	98	0	0	8405	115	0	80	8226	5040	23089.15
34	22	0	35	22	0	37	18	0	40	91.5	0	35	9524	100	0	0	8405	102	0	80	7843	7020	24227.3
35	26	0	35	16	0	37	24	0	40	97.5	0	35	8390	109	0	0	6560	118	0	80	4400	900	14245.15
36	20	0	35	22	0	37	14	0	40	79.5	0	35	9977	81	0	0	10455	53	0	80	13391	21060	42622.5
37	16	0	35	18	0	37	28	0	40	96	0	35	9070	115	0	0	7380	149	0	0	4017	0	13694.3
38	16	0	35	22	0	37	16	0	40	79.5	0	35	10657	82	0	0	11070	77	0	80	13774	17100	40188.35
39	22	0	35	20	0	37	18	0	40	94.5	0	35	9977	113	0	0	8405	144	0	0	5356	0	15929.9
40	22	0	35	18	0	37	20	0	40	90	0	35	9977	97	0	0	9020	97	0	80	8991	9000	27577.1
41	22	0	35	18	0	37	26	0	40	99	0	35	8617	112	0	0	6560	127	0	0	3826	0	13031.5
42	18	0	35	24	0	37	16	0	40	82.5	0	35	9750	84	0	0	9840	63	0	80	12243	18180	38705.95
43	16	0	35	18	0	37	24	0	40	88.5	0	35	9977	103	0	0	9225	122	0	80	8035	3600	21848.1
44	26	0	35	18	0	37	18	0	40	94.5	0	35	9297	107	0	0	7790	111	0	80	5930	3600	19066.55
45	18	0	35	26	0	37	22	0	40	97.5	0	35	8163	107	0	0	6355	107	0	80	4591	3060	16116 7
46	14	0	35	18	0	37	22	0	40	76.5	0	35	10204	77	0	0	11070	47	0	80	14730	23400	46253.35
47	26	0	35	18	0	37	12	0	40	88.5	0	35	10431	107	0	0	9635	137	0	80	7652	540	19216
48	18	0	35	18	0	37	24	0	40	93	0	35	9977	105	0	0	8610	103	0	80	7078	6120	23121.1
49	18	0	35	22	0	37	18	0	40	87	0	35	10431	94	0	0	9840	83	0	80	10330	12780	32707.7
50	28	0	35	20	0	37	22	0	40	106.5	0	35	7936	124	0	0	4920	154	0	0	0	0	8537.75
51	16	0	35	18	0	37	24	0	40	79.5	0	35	9524	75	0	0	10045	80	0	80	14156	16920	39277.2
52	18	0	35	24	0	37	22	0	40	97.5	0	35	8390	117	0	0	6560	159	0	0	2870	0	11881.75

Total Supply Chain Cost (Tk.)= 13,34,995

Appendix B

1. Optimal ordering policies

When,

Generation	Population	Cross Over	Mutation Rate
1000	40	0.25	0.5

WEEK	Retailer 1			Retailer 2			Retailer 3			Distributor			Ware house		Factory		Total supply chain cost (Tk.)
	Customer Demand	*Extra*	**Order** (to distributor)	Customer Demand	*Extra*	**Order** (to distributor)	Customer Demand	*Extra*	**Order** (to distributor)	**Demand from retailer 1,2,3**	*Extra*	**Order** (to warehouse)	*Extra*	**Order** (to factory)	*Extra*	**Order** (to production line)	
1	10	3	13	17	2	19	17	5	22	54	10	64	14	78	10	88	81869.852
2	11	3	14	14	3	17	16	1	17	48	1	49	3	52	0	52	33700.25
3	13	0	13	15	1	16	15	3	18	47	0	47	9	56	8	64	34580.199
4	14	3	17	16	1	17	16	6	22	56	4	60	0	60	14	74	40343.949
5	11	4	15	17	5	22	17	5	22	59	0	59	4	63	15	78	41585.398
6	15	0	15	18	2	20	21	9	30	65	0	65	6	71	5	76	39323.898
7	12	1	13	19	0	19	13	4	17	49	1	50	0	50	4	54	34926.648
8	10	6	16	14	2	16	17	0	17	49	6	55	1	56	10	66	39677
9	13	0	13	16	3	19	15	3	18	50	1	51	7	58	7	65	37199.551
10	15	0	15	17	0	17	11	5	16	48	5	53	2	55	3	58	37060.051
11	13	0	13	15	0	15	12	5	17	45	5	50	2	52	3	55	37227.051
12	15	6	21	14	1	15	13	2	15	51	0	51	2	53	12	65	36651.551
13	10	7	17	16	0	16	15	0	15	48	0	48	16	64	6	70	39943.852
14	11	1	12	17	4	21	13	2	15	48	0	48	4	52	17	69	40548.801
15	12	0	12	14	2	16	17	2	19	47	9	56	5	61	0	61	40268.199
16	14	1	15	15	5	20	12	3	15	50	5	55	4	59	2	61	39149.398
17	15	1	16	19	4	23	11	2	13	52	1	53	2	55	4	59	36309.199
18	12	2	14	18	0	18	15	8	23	55	0	55	3	58	7	65	40552.648
19	11	1	12	15	8	23	14	0	14	49	1	50	1	51	3	54	39135.852
20	10	5	15	16	0	16	16	1	17	48	1	49	0	49	13	62	37730.301
21	11	3	14	17	1	18	14	0	14	46	11	57	0	57	0	57	40311.801
22	10	1	11	16	2	18	17	11	28	57	2	59	3	62	1	63	41824
23	11	2	13	18	2	20	11	2	13	46	3	49	11	60	1	61	42579.199
24	12	1	13	20	1	21	10	2	12	46	1	47	1	48	8	56	38153.148
25	13	9	22	14	4	18	14	4	18	58	0	58	2	60	3	63	43341.398
26	14	1	15	16	8	24	13	0	13	52	0	52	4	56	14	70	40755.852
27	15	2	17	17	0	17	18	2	20	54	0	54	7	61	10	71	36878.199
28	12	4	16	15	1	16	19	1	20	52	0	52	6	58	7	65	40445.352

29	11	3	14	14	1	15	13	3	16	45	6	51	6	57	1	58	41892,75
30	10	0	10	17	1	18	12	8	20	48	3	51	3	54	3	57	41849.5
31	12	6	18	18	2	20	15	0	15	53	3	56	8	64	3	67	43331.949
32	13	4	17	19	0	19	13	4	17	53	5	58	7	65	2	67	42234.301
33	14	4	18	15	3	18	15	4	19	55	0	55	8	63	2	65	42719,602
34	13	1	14	14	13	27	16	2	18	59	2	61	7	68	1	69	44733.199
35	10	1	11	16	3	19	14	0	14	44	2	46	0	46	19	65	41738,199
36	10	0	10	15	7	22	17	1	18	50	0	50	7	57	4	61	41767,801
37	12	0	12	16	4	20	13	4	17	49	0	49	2	51	19	70	41511.699
38	14	2	16	15	8	23	15	1	16	55	0	55	2	57	9	66	42144,898
39	13	5	18	15	2	17	16	4	20	55	1	56	6	62	0	62	43338 5
40	12	2	14	16	0	16	16	7	23	53	1	54	0	54	24	78	43212,699
41	11	5	16	17	2	19	13	2	15	50	1	51	3	54	9	63	42249,148
42	12	4	16	15	0	15	15	0	15	46	3	49	7	56	19	75	44003.199
43	14	1	15	16	1	17	13	6	19	51	1	52	14	66	7	73	43948 648
44	11	0	11	17	1	18	14	0	14	43	0	43	5	48	23	71	39151,398
45	12	1	13	14	1	15	13	1	14	42	0	42	10	52	5	57	40886,75
46	15	6	21	15	2	17	12	1	13	51	0	51	11	62	3	65	44168 699
47	12	4	16	16	0	16	16	3	19	51	0	51	4	55	19	74	42147,199
48	13	5	18	17	3	20	14	0	14	52	4	56	4	60	14	74	43750 898
49	14	2	16	16	0	16	15	1	16	48	8	56	5	61	9	70	43265 699
50	10	5	15	16	1	17	14	1	15	47	2	49	12	61	7	68	44580.102
51	12	10	22	17	0	17	12	1	13	52	0	52	7	59	0	59	43232 648
52	13	4	17	15	11	26	11	2	13	56	1	57	5	62	13	75	50694 398

Total supply chain cost (Tk) = 2164627

GRAPHICAL PRESENTATION

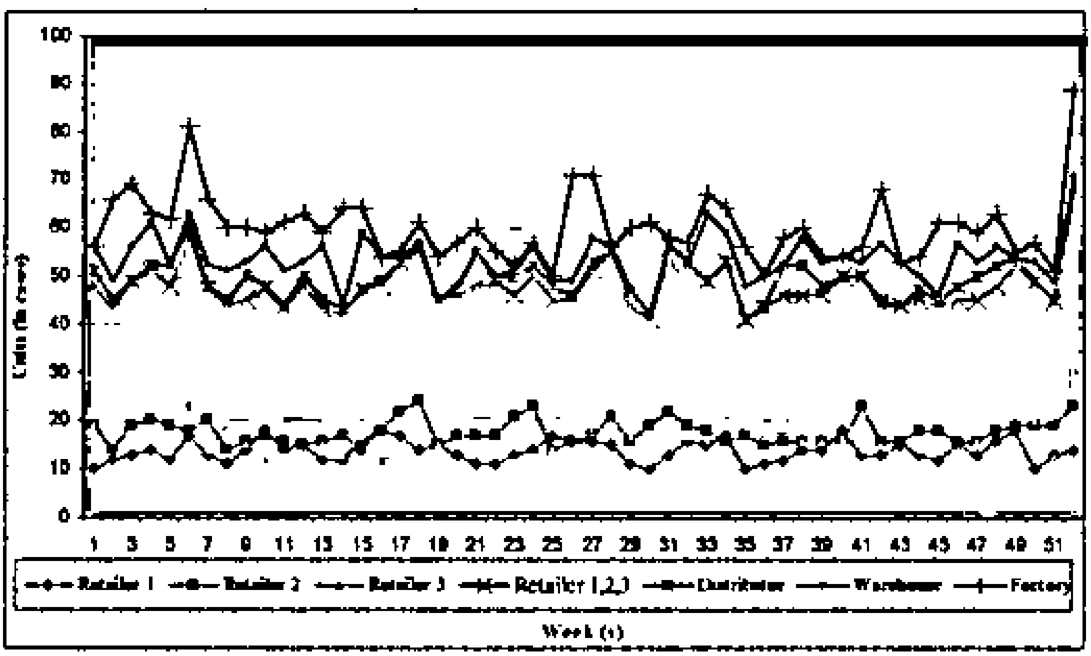

Figure: Graphical presentation of ordering policy for generation 1000, population 40, cross over 0.25, mutation 0.5

2. Optimal ordering policies
When,

Generation	Population	Cross Over	Mutation Rate
1000	40	0.25	1

WEEK	Retailer 1			Retailer 2			Retailer 3			Distributor			Ware house		Factory		*Total supply chain cost* (Tk)
	Customer Demand	*Extra*	Order (to distributor)	Customer Demand	*Extra*	Order (to distributor)	Customer Demand	*Extra*	Order (to distributor)	Demand from retailer 1,2,3	*Extra*	Order (to warehouse)	*Extra*	Order (to factory)	*Extra*	Order (to production line)	
1	10	*3*	**13**	17	*2*	**19**	17	*5*	**22**	54	*10*	**64**	*14*	**78**	*10*	**88**	81869.852
2	11	*5*	**16**	14	*0*	**14**	16	*3*	**19**	49	*5*	**54**	*2*	**56**	*2*	**58**	37440.852
3	13	*1*	**14**	15	*1*	**16**	15	*8*	**23**	53	*1*	**54**	*1*	**55**	*18*	**73**	38951.25
4	14	*9*	**23**	16	*2*	**18**	16	*2*	**18**	59	*0*	**59**	*1*	**60**	*10*	**70**	38091.898
5	11	*2*	**13**	17	*0*	**17**	17	*2*	**19**	49	*3*	**52**	*0*	**52**	*5*	**57**	32434.75
6	15	*2*	**17**	18	*4*	**22**	21	*2*	**23**	62	*0*	**62**	*3*	**65**	*5*	**70**	36243.852
7	12	*2*	**14**	19	*3*	**22**	13	*2*	**15**	51	*3*	**54**	*9*	**63**	*6*	**69**	40156.051
8	10	*3*	**13**	14	*0*	**14**	17	*0*	**17**	44	*1*	**45**	*12*	**57**	*8*	**65**	37410.199
9	13	*8*	**21**	16	*0*	**16**	15	*0*	**15**	52	*5*	**57**	*0*	**57**	*15*	**72**	38464.051
10	15	*2*	**17**	17	*0*	**17**	11	*1*	**12**	46	*3*	**49**	*8*	**57**	*6*	**63**	35650.398
11	13	*0*	**13**	15	*0*	**15**	12	*2*	**14**	42	*7*	**49**	*0*	**49**	*4*	**53**	37240.801
12	15	*0*	**15**	14	*8*	**22**	13	*3*	**16**	53	*0*	**53**	*5*	**58**	*4*	**62**	40046.352
13	10	*3*	**13**	16	*3*	**19**	15	*0*	**15**	47	*1*	**48**	*11*	**59**	*4*	**63**	38810.852
14	11	*1*	**12**	17	*6*	**23**	13	*0*	**13**	48	*0*	**48**	*6*	**54**	*5*	**59**	37779.699
15	12	*1*	**13**	14	*2*	**16**	17	*3*	**20**	49	*4*	**53**	*2*	**55**	*4*	**59**	37970.352
16	14	*4*	**18**	15	*3*	**18**	12	*0*	**12**	48	*3*	**51**	*0*	**51**	*1*	**52**	35479.75
17	15	*0*	**15**	19	*6*	**25**	11	*6*	**17**	57	*6*	**63**	*4*	**67**	*6*	**73**	43757.898
18	12	*4*	**16**	18	*1*	**19**	15	*5*	**20**	55	*0*	**55**	*1*	**56**	*11*	**67**	38660.102
19	11	*1*	**12**	15	*2*	**17**	14	*0*	**14**	43	*1*	**44**	*10*	**54**	*4*	**58**	36659.352
20	10	*5*	**15**	16	*3*	**19**	16	*1*	**17**	51	*1*	**52**	*5*	**57**	*13*	**70**	39733.801
21	11	*0*	**11**	17	*6*	**23**	14	*1*	**15**	49	*4*	**53**	*0*	**53**	*0*	**53**	37187.551
22	10	*0*	**10**	16	*3*	**19**	17	*2*	**19**	48	*2*	**50**	*1*	**51**	*3*	**54**	38262.75
23	11	*3*	**14**	18	*.2*	**20**	11	*2*	**13**	47	*0*	**47**	*2*	**49**	*13*	**62**	38193.852
24	12	*6*	**18**	20	*1*	**21**	10	*0*	**10**	49	*1*	**50**	*3*	**53**	*19*	**72**	41711.102
25	13	*4*	**17**	14	*0*	**14**	14	*1*	**15**	46	*4*	**50**	*3*	**53**	*1*	**54**	38332.699
26	14	*2*	**16**	16	*1*	**17**	13	*8*	**21**	54	*0*	**54**	*7*	**61**	*0*	**61**	39875.602
27	15	*0*	**15**	17	*6*	**23**	18	*0*	**18**	56	*2*	**58**	*4*	**62**	*0*	**62**	37502.602
28	12	*1*	**13**	15	*5*	**20**	19	*0*	**19**	52	*2*	**54**	*11*	**65**	*5*	**70**	42056.25
29	11	*1*	**12**	14	*0*	**14**	13	*2*	**15**	41	*1*	**42**	*2*	**44**	*15*	**59**	36121.199

30	10	0	10	17	3	20	12	3	15	45	3	48	3	51	1	52	40204.801
31	12	2	14	18	3	21	15	1	16	51	3	54	1	55	2	57	38473.398
32	13	0	13	19	3	22	13	2	15	50	0	50	21	71	0	71	41789.449
33	14	2	16	15	14	29	15	1	16	61	0	61	0	61	1	62	41856.102
34	13	0	13	14	1	15	16	1	17	45	4	49	0	49	23	72	39917.199
35	10	0	10	16	3	19	14	5	19	48	1	49	2	51	5	56	37972.449
36	10	1	11	15	0	15	17	0	17	43	4	47	0	47	18	65	39177.699
37	12	5	17	16	1	17	13	0	13	47	0	47	1	48	19	67	40482.352
38	14	9	23	15	0	15	15	4	19	57	2	59	1	60	8	68	43436.449
39	13	7	20	15	1	16	16	0	16	52	0	52	8	60	1	61	41198.148
40	12	2	14	16	0	16	16	2	18	48	8	56	3	59	3	62	42218.449
41	11	2	13	17	1	18	13	1	14	45	0	45	5	50	1	51	37738.051
42	12	3	15	15	2	17	15	3	18	50	2	52	1	53	0	53	39199.801
43	14	0	14	16	0	16	13	8	21	51	3	54	6	60	6	66	44936.301
44	11	1	12	17	3	20	14	3	17	49	1	50	9	59	0	59	41310.102
45	12	0	12	14	1	15	13	9	22	49	0	49	8	57	1	58	43706.301
46	15	3	18	15	3	18	12	6	18	54	1	55	0	55	0	55	41714.699
47	12	0	12	16	1	17	16	3	19	48	0	48	3	51	1	52	37634.449
48	13	0	13	17	0	17	14	0	14	44	3	47	9	56	7	63	38746.852
49	14	3	17	16	10	26	15	7	22	65	1	66	0	66	11	77	47315.25
50	10	1	11	16	7	23	14	0	14	48	4	52	4	56	2	58	42306.352
51	12	5	17	17	2	19	12	0	12	48	0	48	4	52	12	64	42472.199
52	13	11	24	15	4	19	11	8	19	62	0	62	1	63	12	75	50798.051

Total supply chain cost (Tk.)= 2106701

GRAPHICAL PRESENTATION

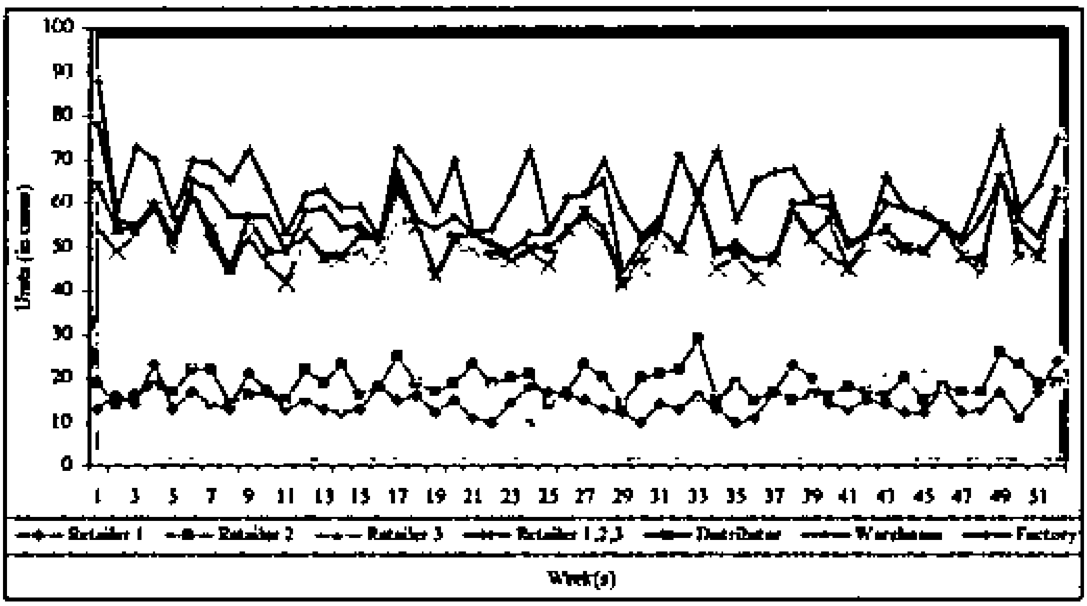

Figure: Graphical presentation of ordering policy for generation1000, population 40, cross over 0.25, mulation 1.

3. Optimal ordering policies

When,

Generation	Population	Cross Over	Mutation Rate
1000	80	0.25	0.5

WEEK	Retailer 1			Retailer 2			Retailer 3			Distributor			Ware house		Factory		Total supply chain cost (Tk)
	Customer Demand	*Extra*	Order (to distributor)	Customer Demand	*Extra*	Order (to distributor)	Customer Demand	*Extra*	Order (to distributor)	Demand from retailer 1,2,3	*Extra*	Order (to warehouse)	*Extra*	Order (to factory)	*Extra*	Order (to production line)	
1	10	*1*	**11**	17	*1*	**18**	17	*4*	**21**	50	*1*	**51**	*2*	**53**	*7*	**60**	22578 15
2	11	*0*	**11**	14	*0*	**14**	16	*1*	**17**	42	*0*	**42**	*13*	**55**	*1*	**56**	9201 25
3	13	*4*	**17**	15	*0*	**15**	15	*1*	**16**	48	*0*	**48**	*6*	**54**	*11*	**65**	10914 35
4	14	*0*	**14**	16	*2*	**18**	16	*5*	**21**	53	*0*	**53**	*3*	**56**	*7*	**63**	10259.35
5	11	*1*	**12**	17	*1*	**18**	17	*0*	**17**	47	*5*	**52**	*2*	**54**	*15*	**69**	11486.45
6	15	*0*	**15**	18	*9*	**27**	21	*0*	**21**	63	*1*	**64**	*1*	**65**	*8*	**73**	11739.2
7	12	*1*	**13**	19	*2*	**21**	13	*0*	**13**	47	*3*	**50**	*7*	**57**	*1*	**58**	10341 7
8	10	*2*	**12**	14	*2*	**16**	17	*3*	**20**	48	*2*	**50**	*10*	**60**	*6*	**66**	14441.25
9	13	*0*	**13**	16	*0*	**16**	15	*0*	**15**	44	*2*	**46**	*4*	**50**	*4*	**54**	7366 5
10	15	*2*	**17**	17	*1*	**18**	11	*6*	**17**	52	*5*	**57**	*1*	**58**	*1*	**59**	13234.3
11	13	*2*	**15**	15	*1*	**16**	12	*0*	**12**	43	*9*	**52**	*3*	**55**	*1*	**56**	12943.8
12	15	*6*	**21**	14	*1*	**15**	13	*1*	**14**	50	*0*	**50**	*1*	**51**	*1*	**52**	9824
13	10	*4*	**14**	16	*0*	**16**	15	*5*	**20**	50	*0*	**50**	*4*	**54**	*1*	**55**	11775.95
14	11	*7*	**18**	17	*1*	**18**	13	*1*	**14**	50	*5*	**55**	*3*	**58**	*4*	**62**	15230 8
15	12	*0*	**12**	14	*1*	**15**	17	*1*	**18**	45	*3*	**48**	*3*	**51**	*9*	**60**	10655 85
16	14	*2*	**16**	15	*1*	**16**	12	*0*	**12**	44	*0*	**44**	*3*	**47**	*7*	**54**	9149 1504
17	15	*1*	**16**	19	*6*	**25**	11	*2*	**13**	54	*0*	**54**	*1*	**55**	*1*	**56**	11037 05
18	12	*1*	**13**	18	*0*	**18**	15	*0*	**15**	46	*7*	**53**	*9*	**62**	*6*	**68**	14696 9
19	11	*3*	**14**	15	*2*	**17**	14	*1*	**15**	46	*4*	**50**	*9*	**59**	*0*	**59**	14948 2
20	10	*4*	**14**	16	*2*	**18**	16	*0*	**16**	48	*4*	**52**	*2*	**54**	*1*	**55**	12540.4
21	11	*3*	**14**	17	*3*	**20**	14	*1*	**15**	49	*0*	**49**	*2*	**51**	*0*	**51**	10557 95
22	10	*2*	**12**	16	*2*	**18**	17	*1*	**18**	48	*1*	**49**	*6*	**55**	*3*	**58**	12214
23	11	*2*	**13**	18	*3*	**21**	11	*0*	**11**	45	*0*	**45**	*6*	**51**	*8*	**59**	12644 45
24	12	*1*	**13**	20	*1*	**21**	10	*1*	**11**	45	*1*	**46**	*1*	**47**	*1*	**48**	8758.7998
25	13	*4*	**17**	14	*1*	**15**	14	*4*	**18**	50	*2*	**52**	*2*	**54**	*4*	**58**	14225.35
26	14	*1*	**15**	16	*4*	**20**	13	*0*	**13**	48	*2*	**50**	*1*	**51**	*15*	**66**	13576.15
27	15	*0*	**15**	17	*3*	**20**	18	*1*	**19**	54	*0*	**54**	*3*	**57**	*9*	**66**	11415.8
28	12	*2*	**14**	15	*2*	**17**	19	*2*	**21**	52	*4*	**56**	*6*	**62**	*6*	**68**	15965 1
29	11	*3*	**14**	14	*0*	**14**	13	*2*	**15**	43	*1*	**44**	*8*	**52**	*11*	**63**	15316

30	10	*2*	12	17	*3*	20	12	*1*	13	45	*8*	53	*0*	53	*2*	55	15542.3
31	12	*0*	12	18	*2*	20	15	*1*	16	48	*0*	48	*2*	50	*15*	65	12080 25
32	13	*0*	13	19	*0*	19	13	*0*	13	45	*5*	50	*2*	52	*14*	66	13247.05
33	14	*3*	17	15	*0*	15	15	*0*	15	47	*1*	48	*3*	51	*17*	68	13692.2
34	13	*2*	15	14	*1*	15	16	*3*	19	49	*1*	50	*3*	53	*12*	65	14693.85
35	10	*7*	17	16	*0*	16	14	*0*	14	47	*0*	47	*3*	50	*7*	57	13828 35
36	10	*3*	13	15	*0*	15	17	*8*	25	53	*4*	57	*1*	58	*2*	60	17208 65
37	12	*4*	16	16	*0*	16	13	*1*	14	46	*0*	46	*6*	52	*13*	65	15141.95
38	14	*0*	14	15	*2*	17	15	*2*	17	48	*4*	52	*2*	54	*6*	60	14134.8
39	13	*1*	14	15	*0*	15	16	*2*	18	47	*3*	50	*9*	59	*8*	67	16147.4
40	12	*11*	23	16	*0*	16	16	*2*	18	57	*0*	57	*5*	62	*0*	62	17525.15
41	11	*2*	13	17	*1*	18	13	*0*	13	44	*7*	51	*0*	51	*2*	53	14150.1
42	12	*0*	12	15	*1*	16	15	*0*	15	43	*3*	46	*5*	51	*3*	54	12687.6
43	14	*6*	20	16	*1*	17	13	*0*	13	50	*1*	51	*11*	62	*2*	64	17484.301
44	11	*2*	13	17	*0*	17	14	*1*	15	45	*3*	48	*1*	49	*8*	57	13492
45	12	*0*	12	14	*0*	14	13	*1*	14	40	*0*	40	*4*	44	*5*	49	11074.75
46	15	*3*	18	15	*2*	17	12	*0*	12	47	*2*	49	*8*	57	*0*	57	15592.75
47	12	*3*	15	16	*0*	16	16	*0*	16	47	*0*	47	*4*	51	*10*	61	13600 35
48	13	*0*	13	17	*0*	17	14	*3*	17	47	*0*	47	*6*	53	*0*	53	12525.95
49	14	*0*	14	16	*4*	20	15	*0*	15	49	*0*	49	*9*	58	*8*	66	15985.3
50	10	*5*	15	16	*1*	17	14	*1*	15	47	*1*	48	*5*	53	*4*	57	16287.1
51	12	*3*	15	17	*1*	18	12	*2*	14	47	*1*	48	*1*	49	*22*	71	17664.25
52	13	*4*	17	15	*6*	21	11	*1*	12	50	*8*	58	*18*	76	*16*	92	30904.15

Total supply chain cost (Tk) = 7,13,728 875

GRAPHICAL PRESENTATION

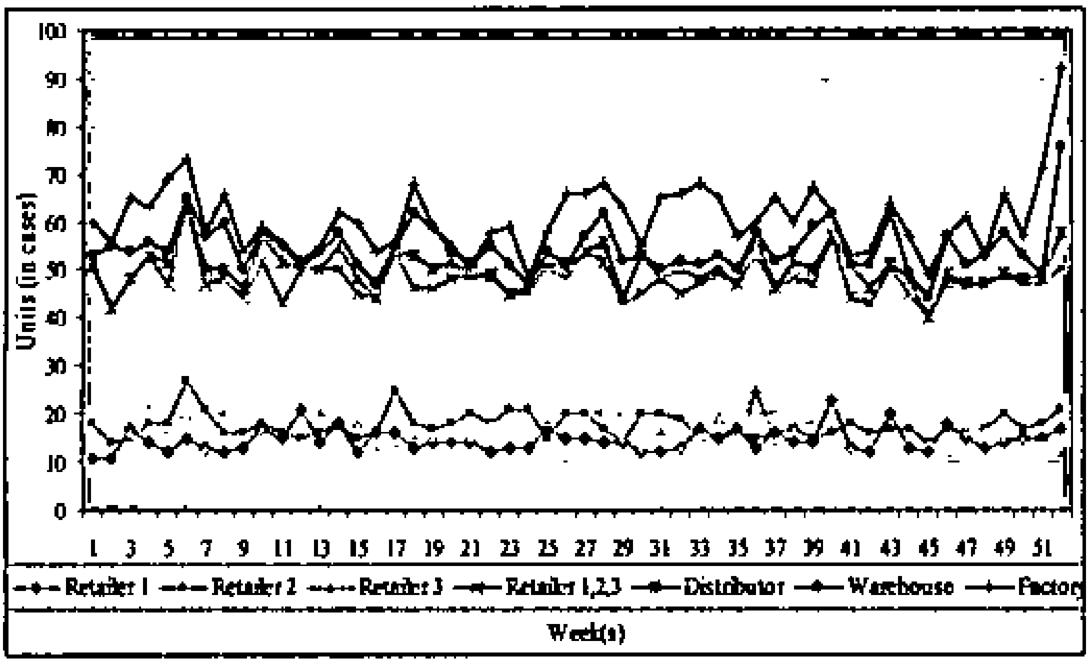

Figure: Graphical presentation of ordering policy for generation1000, population 80, cross over 0.25, mutation 0.5

4. Optimal ordering policies

When,

Generation	Population	Cross Over	Mutation Rate
20000	40	0.25	1

WEEK	Retailer 1			Retailer 2			Retailer 3			Distributor			Ware house		Factory		*Total supply chain cost* (Tk.)
	Customer Demand	*Extra*	**Order** (to distributor)	**Customer Demand**	*Extra*	**Order** (to distributor)	**Customer Demand**	*Extra*	**Order** (to distributor)	**Demand from retailer 1,2,3**	*Extra*	**Order** (to warehouse)	*Extra*	**Order** (to factory)	*Extra*	**Order** (to production line)	
1	10	*3*	**13**	17	*2*	**19**	17	*5*	**22**	54	*10*	**64**	*14*	**78**	*10*	**88**	81869.852
2	11	*3*	**14**	14	*3*	**17**	16	*3*	**19**	50	*1*	**51**	*0*	**51**	*12*	**63**	35452
3	13	*0*	**13**	15	*1*	**16**	15	*3*	**18**	47	*1*	**48**	*7*	**55**	*19*	**74**	36535.949
4	14	*9*	**23**	16	*2*	**18**	16	*3*	**19**	60	*0*	**60**	*3*	**63**	*1*	**64**	38396 898
5	11	*4*	**15**	17	*1*	**18**	17	*4*	**21**	54	*5*	**59**	*3*	**62**	*2*	**64**	37431.102
6	15	*0*	**15**	18	*0*	**18**	21	*12*	**33**	66	*1*	**67**	*4*	**71**	*2*	**73**	40446.602
7	12	*6*	**18**	19	*0*	**19**	13	*0*	**13**	50	*3*	**53**	*1*	**54**	*4*	**58**	35324 949
8	10	*0*	**10**	14	*1*	**15**	17	*2*	**19**	44	*0*	**44**	*11*	**55**	*2*	**57**	38347.301
9	13	*0*	**13**	16	*0*	**16**	15	*2*	**17**	46	*0*	**46**	*2*	**48**	*14*	**62**	35919 102
10	15	*11*	**26**	17	*1*	**18**	11	*0*	**11**	55	*7*	**62**	*0*	**62**	*3*	**65**	40029 75
11	13	*4*	**17**	15	*2*	**17**	12	*2*	**14**	48	*1*	**49**	*3*	**52**	*4*	**56**	38441.699
12	15	*1*	**16**	14	*8*	**22**	13	*0*	**13**	51	*1*	**52**	*5*	**57**	*0*	**57**	37399
13	10	*0*	**10**	16	*0*	**16**	15	*0*	**15**	41	*7*	**48**	*10*	**58**	*0*	**58**	38879.449
14	11	*2*	**13**	17	*0*	**17**	13	*0*	**13**	43	*4*	**47**	*0*	**47**	*11*	**58**	37787 801
15	12	*2*	**14**	14	*4*	**18**	17	*2*	**19**	51	*0*	**51**	*3*	**54**	*8*	**62**	37891.75
16	14	*0*	**14**	15	*9*	**24**	12	*4*	**16**	54	*2*	**56**	*2*	**58**	*16*	**74**	41689 051
17	15	*2*	**17**	19	*1*	**20**	11	*1*	**12**	49	*1*	**50**	*6*	**56**	*8*	**64**	39286.648
18	12	*8*	**20**	18	*1*	**19**	15	*1*	**16**	55	*0*	**55**	*2*	**57**	*1*	**58**	37748 449
19	11	*0*	**11**	15	*0*	**15**	14	*5*	**19**	45	*0*	**45**	*8*	**53**	*0*	**53**	37586.75
20	10	*3*	**13**	16	*13*	**29**	16	*2*	**18**	60	*2*	**62**	*1*	**63**	*5*	**68**	42863.699
21	11	*2*	**13**	17	*0*	**17**	14	*4*	**18**	48	*2*	**50**	*3*	**53**	*1*	**54**	37319.648
22	10	*1*	**11**	16	*0*	**16**	17	*4*	**21**	48	*2*	**50**	*2*	**52**	*9*	**61**	38574 75
23	11	*4*	**15**	18	*2*	**20**	11	*0*	**11**	46	*1*	**47**	*7*	**54**	*3*	**57**	40743 551
24	12	*2*	**14**	20	*1*	**21**	10	*2*	**12**	47	*2*	**49**	*0*	**49**	*12*	**61**	39158 102
25	13	*2*	**15**	14	*1*	**15**	14	*1*	**15**	45	*8*	**53**	*0*	**53**	*10*	**63**	42623.801
26	14	*0*	**14**	16	*1*	**17**	13	*2*	**15**	46	*2*	**48**	*6*	**54**	*4*	**58**	37732.301
27	15	*2*	**17**	17	*1*	**18**	18	*3*	**21**	56	*4*	**60**	*3*	**63**	*0*	**63**	38356.398
28	12	*2*	**14**	15	*1*	**16**	19	*3*	**22**	52	*0*	**52**	*4*	**56**	*4*	**60**	38445.801
29	11	*1*	**12**	14	*4*	**18**	13	*2*	**15**	45	*0*	**45**	*8*	**53**	*10*	**63**	39426.648
30	10	*3*	**13**	17	*3*	**20**	12	*2*	**14**	47	*1*	**48**	*5*	**53**	*9*	**62**	41303.699

31	12	0	12	18	6	24	15	0	15	51	1	52	2	54	11	65	40605.398
32	13	3	16	19	0	19	13	2	15	50	5	55	4	59	2	61	39781.301
33	14	2	16	15	3	18	15	0	15	49	0	49	5	54	14	68	40082
34	13	4	17	14	1	15	16	3	19	51	3	54	0	54	1	55	39423.898
35	10	3	13	16	0	16	14	0	14	43	3	46	10	56	7	63	40908.398
36	10	6	16	15	1	16	17	2	19	51	1	52	3	55	7	62	40138.449
37	12	4	16	16	2	18	13	1	14	48	2	50	5	55	4	59	41055.199
38	14	1	15	15	2	17	15	3	18	50	0	50	12	62	15	77	43529.398
39	13	3	16	15	9	24	16	2	18	58	0	58	9	67	4	71	45315.602
40	12	2	14	16	1	17	16	4	20	51	6	57	1	58	1	59	41041.25
41	11	7	18	17	4	21	13	1	14	53	2	55	1	56	3	59	42799.949
42	12	5	17	15	0	15	15	5	20	52	0	52	2	54	0	54	42715.352
43	14	6	20	16	0	16	13	0	13	49	2	51	5	56	8	64	39929.199
44	11	1	12	17	3	20	14	0	14	46	2	48	4	52	13	65	40576.398
45	12	0	12	14	0	14	13	6	19	45	1	46	0	46	2	48	36961.898
46	15	1	16	15	3	18	12	0	12	46	0	46	6	52	16	68	42177.898
47	12	3	15	16	1	17	16	0	16	48	0	48	2	50	7	57	38395.949
48	13	3	16	17	5	22	14	0	14	52	2	54	6	60	20	80	45701.301
49	14	3	17	16	3	19	15	4	19	55	1	56	3	59	8	67	42282.801
50	10	1	11	16	1	17	14	4	18	46	1	47	5	52	11	63	43804.301
51	12	2	14	17	7	24	12	0	12	50	0	50	5	55	4	59	40709.051
52	13	11	24	15	13	28	11	4	15	67	4	71	17	88	19	107	66655.602

Total supply chain cost (Tk)= 21,37,603

GRAPHICALPRESENTATION

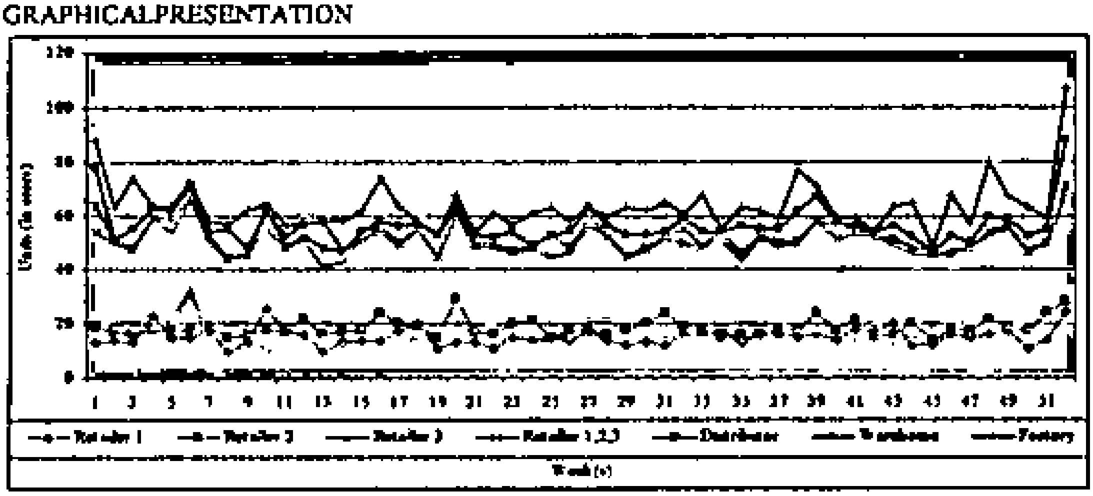

Figure: Graphical presentation of ordering policy for generation 20000, population 40, crossover 0.25, mutation 1.

Appendix C

Results

1. Optimal ordering policies
When,

Generation	Population	Cross Over	Mutation Rate
1000	40	0.25	1

WEEK	Retailer 1			Retailer 2			Retailer 3			Distributor			Ware house		Factory		*Total supply chain cost* (Tk.)
	Customer Demand	*Extra*	**Order** (to distributor)	**Customer Demand**	*Extra*	**Order** (to distributor)	**Customer Demand**	*Extra*	**Order** (to distributor)	**Demand from retailer 1,2,3**	*Extra*	**Order** (to warehouse)	*Extra*	**Order** (to factory)	*Extra*	**Order** (to production line)	
1	10	*3*	**13**	17	*2*	**19**	17	*5*	**22**	54	*10*	**64**	*14*	**78**	*10*	**88**	81869.852
2	11	*1*	**12**	14	*0*	**14**	16	*0*	**16**	42	*0*	**42**	*0*	**42**	*0*	**42**	29375.1
3	13	*1*	**14**	15	*0*	**15**	15	*2*	**17**	46	2	**48**	*0*	**48**	*1*	**49**	30892.5
4	14	*1*	**15**	16	*0*	**16**	16	*2*	**18**	49	*1*	**50**	*0*	**50**	*1*	**51**	30952 5
5	11	*0*	**11**	17	*1*	**18**	17	*0*	**17**	46	*0*	**46**	*0*	**46**	*5*	**51**	29300.5
6	15	*3*	**18**	18	*0*	**18**	21	*1*	**22**	58	*0*	**58**	*6*	**64**	*0*	**64**	32092 9
7	12	*1*	**13**	19	*0*	**19**	13	*0*	**13**	45	*0*	**45**	*2*	**47**	*5*	**52**	29667.051
8	10	*2*	**12**	14	*0*	**14**	17	*0*	**17**	43	*1*	**44**	*1*	**45**	*3*	**48**	31437.35
9	13	*2*	**15**	16	*0*	**16**	15	*0*	**15**	46	*2*	**48**	*2*	**50**	*5*	**55**	31689 199
10	15	*2*	**17**	17	*0*	**17**	11	*0*	**11**	45	*1*	**46**	*0*	**46**	*6*	**52**	30584 85
11	13	*2*	**15**	15	*0*	**15**	12	*0*	**12**	42	*1*	**43**	*0*	**43**	*1*	**44**	31658 5
12	15	*2*	**17**	14	*0*	**14**	13	*1*	**14**	45	*0*	**45**	*3*	**48**	*4*	**52**	31741.15
13	10	*1*	**11**	16	*1*	**17**	15	*1*	**16**	44	*3*	**47**	*0*	**47**	*2*	**49**	32167 801
14	11	*0*	**11**	17	*1*	**18**	13	*3*	**16**	45	*0*	**45**	*3*	**48**	*1*	**49**	32061.301
15	12	*0*	**12**	14	*1*	**15**	17	*2*	**19**	46	*3*	**49**	*1*	**50**	*1*	**51**	32615.801
16	14	*0*	**14**	15	*1*	**16**	12	*1*	**13**	43	*0*	**43**	*0*	**43**	*2*	**45**	32528.801
17	15	*5*	**20**	19	*0*	**19**	11	*0*	**11**	50	*1*	**51**	*3*	**54**	*3*	**57**	34637.051
18	12	*1*	**13**	18	*0*	**18**	15	*3*	**18**	49	*0*	**49**	*0*	**49**	*0*	**49**	32373 199
19	11	*1*	**12**	15	*1*	**16**	14	*0*	**14**	42	*0*	**42**	*3*	**45**	*1*	**46**	33907 398
20	10	*0*	**10**	16	*1*	**17**	16	*0*	**16**	43	*2*	**45**	*1*	**46**	*3*	**49**	32440.301
21	11	*0*	**11**	17	*1*	**18**	14	*0*	**14**	43	*5*	**48**	*0*	**48**	*5*	**53**	33771.699
22	10	*1*	**11**	16	*1*	**17**	17	*2*	**19**	47	*1*	**48**	*0*	**48**	*3*	**51**	32873.051
23	11	*1*	**12**	18	*1*	**19**	11	*0*	**11**	42	*0*	**42**	*2*	**44**	*6*	**50**	33705.5
24	12	*1*	**13**	20	*0*	**20**	10	*0*	**10**	43	*0*	**43**	*1*	**44**	*1*	**45**	33046.75
25	13	*1*	**14**	14	*0*	**14**	14	*0*	**14**	42	*1*	**43**	*0*	**43**	7	**50**	32042.1

26	14	1	15	16	2	18	13	3	16	49	0	49	0	49	4	53	34102.398
27	15	0	15	17	0	17	18	0	18	50	2	52	0	52	9	61	33886.801
28	12	1	13	15	1	16	19	1	20	49	0	49	0	49	7	56	33059,148
29	11	0	11	14	1	15	13	0	13	39	0	39	2	41	0	41	33210 699
30	10	1	11	17	0	17	12	0	12	40	2	42	1	43	8	51	33884.75
31	12	1	13	18	1	19	15	0	15	47	1	48	4	52	2	54	35284 949
32	13	3	16	19	0	19	13	3	16	51	0	51	1	52	6	58	35610,301
33	14	2	16	15	0	15	15	0	15	46	3	49	1	50	3	53	36359.5
34	13	0	13	14	3	17	16	2	18	48	1	49	1	50	0	50	35249.551
35	10	3	13	16	0	16	14	0	14	43	3	46	1	47	8	55	36893,949
36	10	1	11	15	2	17	17	0	17	45	2	47	2	49	4	53	35400,949
37	12	0	12	16	1	17	13	0	13	42	2	44	0	44	0	44	34528 199
38	14	0	14	15	0	15	15	0	15	44	3	47	5	52	1	53	34904 852
39	13	1	14	15	2	17	16	0	16	47	1	48	0	48	2	50	33826 699
40	12	0	12	16	1	17	16	1	17	46	0	46	0	46	7	53	34911.199
41	11	1	12	17	0	17	13	2	15	44	3	47	1	48	5	53	36300
42	12	0	12	15	1	16	15	0	15	43	2	45	4	49	0	49	36005,352
43	14	0	14	16	0	16	13	0	13	43	4	47	6	53	3	56	36850 801
44	11	2	13	17	0	17	14	0	14	44	0	44	2	46	9	55	35254 301
45	12	0	12	14	0	14	13	0	13	39	6	45	0	45	2	47	37575,949
46	15	0	15	15	2	17	12	2	14	46	2	48	1	49	3	52	36433,398
47	12	2	14	16	4	20	16	1	17	51	0	51	0	51	3	54	36838.148
48	13	2	15	17	0	17	14	2	16	48	0	48	0	48	5	53	36028.648
49	14	0	14	16	3	19	15	0	15	48	1	49	0	49	0	49	35775,199
50	10	2	12	16	0	16	14	2	16	44	1	45	1	46	3	49	37541,449
51	12	2	14	17	2	19	12	0	12	45	1	46	0	46	0	46	35435,148
52	13	0	13	15	0	15	11	0	11	39	6	45	7	52	9	61	43188,199

Total supply chain cost (Tk)= 1813773

GRAPHICAL PRESENTATION

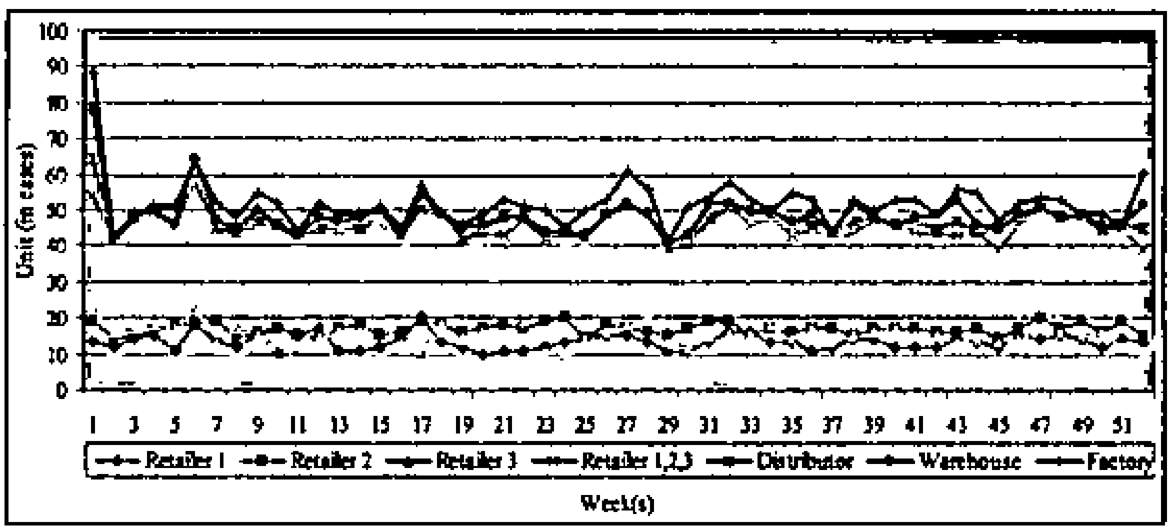

Figure: Graphical presentation of ordering policy for generation1000, population 40, cross over 0.25, mutation 1 for analysis 2

29	11	0	11	14	1	15	13	0	13	39	2	41	2	43	3	46	34419.648
30	10	1	11	17	0	17	12	0	12	40	0	40	0	40	1	41	32127.35
31	12	0	12	18	0	18	15	1	16	46	0	46	9	55	5	60	35980.199
32	13	2	15	19	0	19	13	1	14	48	0	48	0	48	2	50	35049.852
33	14	1	15	15	0	15	15	0	15	45	1	46	1	47	6	53	35060.25
34	13	0	13	14	0	14	16	0	16	43	2	45	0	45	6	51	34124.898
35	10	1	11	16	3	19	14	0	14	44	3	47	0	47	4	51	35726.449
36	10	0	10	15	0	15	17	2	19	44	3	47	3	50	0	50	36271.148
37	12	1	13	16	0	16	13	2	15	44	6	50	2	52	3	55	37793.852
38	14	1	15	15	0	15	15	2	17	47	0	47	1	48	4	52	35763.699
39	13	3	16	15	0	15	16	0	16	47	1	48	3	51	3	54	35214.898
40	12	0	12	16	0	16	16	1	17	45	0	45	1	46	1	47	34145.699
41	11	1	12	17	1	18	13	0	13	43	1	44	4	48	3	51	37098.301
42	12	0	12	15	1	16	15	3	18	46	1	47	3	50	1	51	37055.449
43	14	2	16	16	2	18	13	1	14	48	0	48	4	52	1	53	37544.75
44	11	1	12	17	0	17	14	0	14	43	3	46	3	49	9	58	37526.75
45	12	1	13	14	0	14	13	0	13	40	0	40	1	41	9	50	36198.102
46	15	0	15	15	0	15	12	4	16	46	0	46	0	46	0	46	36695.301
47	12	1	13	16	0	16	16	3	19	48	2	50	0	50	5	55	37218.75
48	13	0	13	17	1	18	14	1	15	46	0	46	0	46	4	50	36450.398
49	14	2	16	16	0	16	15	0	15	47	0	47	2	49	1	50	36135.051
50	10	1	11	16	0	16	14	0	14	41	1	42	1	43	7	50	37056.551
51	12	0	12	17	2	19	12	0	12	43	0	43	0	43	0	43	33555
52	13	1	14	15	0	15	11	1	12	41	0	41	6	47	8	55	41340.5

Total supply chain cost (Tk)= 18,30,956

GRAPHICAL PRESENTATION

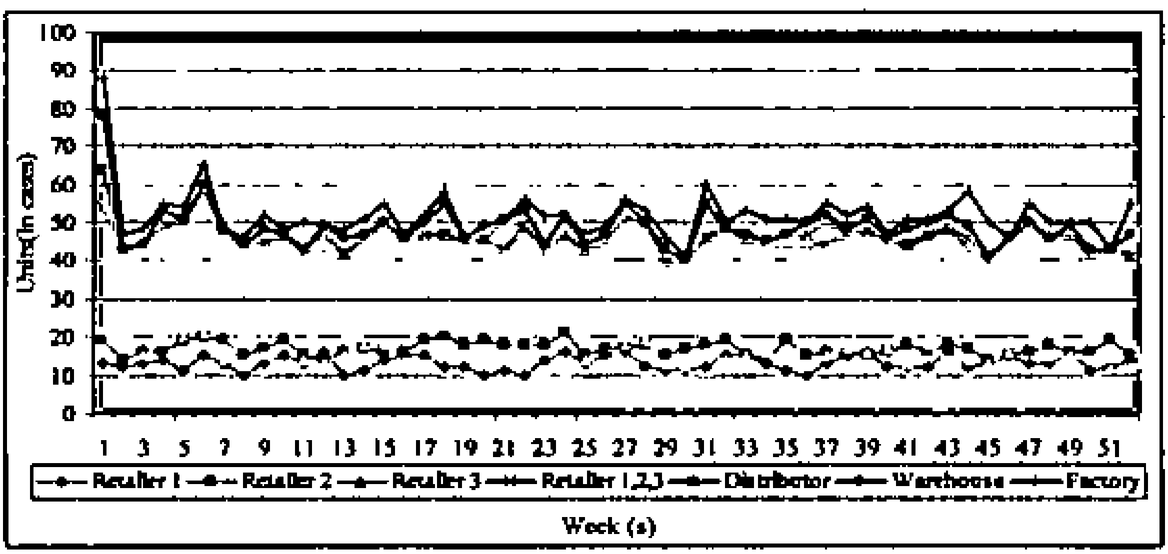

Figure: Graphical presentation of ordering policy for generation 20000, population 40, cross over 0.25, mutation 0.5 for analysis 2

3. Optimal ordering policies

When,

Generation	Population	Cross Over	Mutation Rate
10000	40	0.5	0.5

WEEK	**Retailer 1**			**Retailer 2**			**Retailer 3**			**Distributor**			**Ware house**		**Factory**		
	Customer Demand	*Extra*	**Order** (to distributor)	**Customer Demand**	*Extra*	**Order** (to distributor)	**Customer Demand**	*Extra*	**Order** (to distributor)	**Demand from retailer 1,2,3**	*Extra*	**Order** (to warehouse)	*Extra*	**Order** (to factory)	*Extra*	**Order** (to production line)	***Total supply chain cost* (Tk.)**
1	10	*3*	**13**	17	*2*	**19**	17	*5*	**22**	54	*10*	**64**	*14*	**78**	*10*	**88**	81869.852
2	11	*1*	**12**	14	*1*	**15**	16	*0*	**16**	43	*0*	**43**	*6*	**49**	*1*	**50**	30714.1
3	13	*1*	**14**	15	*0*	**15**	15	*0*	**15**	44	*0*	**44**	*4*	**48**	*1*	**49**	29983.5
4	14	*1*	**15**	16	*2*	**18**	16	*1*	**17**	50	*0*	**50**	*3*	**53**	*1*	**54**	30900.301
5	11	*0*	**11**	17	*0*	**17**	17	*3*	**20**	48	*0*	**48**	*0*	**48**	*3*	**51**	31416.1
6	15	*0*	**15**	18	*0*	**18**	21	*1*	**22**	55	*2*	**57**	*0*	**57**	*4*	**61**	31099.35
7	12	*0*	**12**	19	*0*	**19**	13	*0*	**13**	44	*0*	**44**	*2*	**46**	*5*	**51**	30288.1
8	10	*0*	**10**	14	*0*	**14**	17	*0*	**17**	41	*0*	**41**	*4*	**45**	*2*	**47**	30562.801
9	13	*0*	**13**	16	*0*	**16**	15	*0*	**15**	44	*0*	**44**	*4*	**48**	*2*	**50**	30649.801
10	15	*0*	**15**	17	*1*	**18**	11	*4*	**15**	48	*0*	**48**	*0*	**48**	*2*	**50**	32316.85
11	13	*0*	**13**	15	*1*	**16**	12	*1*	**13**	42	*2*	**44**	*1*	**45**	*8*	**53**	32166.801
12	15	*1*	**16**	14	*0*	**14**	13	*0*	**13**	43	*0*	**43**	*2*	**45**	*8*	**53**	32108.051
13	10	*0*	**10**	16	*3*	**19**	15	*1*	**16**	45	*0*	**45**	*3*	**48**	*0*	**48**	32971.102
14	11	*1*	**12**	17	*0*	**17**	13	*0*	**13**	42	*1*	**43**	*0*	**43**	*6*	**49**	31823.9
15	12	*2*	**14**	14	*0*	**14**	17	*0*	**17**	45	*0*	**45**	*1*	**46**	*0*	**46**	31786.449
16	14	*0*	**14**	15	*0*	**15**	12	*0*	**12**	41	*1*	**42**	*2*	**44**	*3*	**47**	32267.6
17	15	*1*	**16**	19	*0*	**19**	11	*0*	**11**	46	*0*	**46**	*0*	**46**	*0*	**46**	30974.1
18	12	*0*	**12**	18	*2*	**20**	15	*0*	**15**	47	*0*	**47**	*3*	**50**	*3*	**53**	32893.898
19	11	*0*	**11**	15	*0*	**15**	14	*1*	**15**	41	*2*	**43**	*1*	**44**	*7*	**51**	32403.449
20	10	*0*	**10**	16	*1*	**17**	16	*1*	**17**	44	*5*	**49**	*0*	**49**	*0*	**49**	33344.25
21	11	*1*	**12**	17	*0*	**17**	14	*0*	**14**	43	*2*	**45**	*0*	**45**	*1*	**46**	32989.5
22	10	*0*	**10**	16	*0*	**16**	17	*0*	**17**	43	*1*	**44**	*1*	**45**	*4*	**49**	34071.699
23	11	*4*	**15**	18	*2*	**20**	11	*0*	**11**	46	*2*	**48**	*2*	**50**	*0*	**50**	35059.898
24	12	*0*	**12**	20	*2*	**22**	10	*0*	**10**	44	*1*	**45**	*0*	**45**	*3*	**48**	31795.949
25	13	*1*	**14**	14	*0*	**14**	14	*1*	**15**	43	*0*	**43**	*5*	**48**	*1*	**49**	32874.801
26	14	*0*	**14**	16	*1*	**17**	13	*0*	**13**	44	*0*	**44**	*5*	**49**	*2*	**51**	33195.102
27	15	*1*	**16**	17	*2*	**19**	18	*1*	**19**	54	*0*	**54**	*0*	**54**	*3*	**57**	32737
28	12	*0*	**12**	15	*2*	**17**	19	*0*	**19**	48	*0*	**48**	*5*	**53**	*6*	**59**	34230.301

29	11	0	11	14	0	14	13	0	13	38	1	39	0	39	3	42	33616.051
30	10	0	10	17	1	18	12	0	12	40	2	42	0	42	0	42	31940.051
31	12	0	12	18	1	19	15	0	15	46	0	46	0	46	5	51	34264.648
32	13	1	14	19	2	21	13	0	13	48	0	48	0	48	3	51	32750.949
33	14	2	16	15	0	15	15	0	15	46	1	47	2	49	0	49	33679.699
34	13	0	13	14	0	14	16	1	17	44	1	45	1	46	2	48	33751
35	10	0	10	16	1	17	14	4	18	45	2	47	1	48	2	50	36985.25
36	10	0	10	15	2	17	17	0	17	44	3	47	4	51	3	54	36626.301
37	12	0	12	16	1	17	13	2	15	44	2	46	0	46	8	54	35459.551
38	14	4	18	15	0	15	15	0	15	48	1	49	2	51	6	57	35932.551
39	13	2	15	15	0	15	16	0	16	46	0	46	1	47	2	49	34841.051
40	12	1	13	16	1	17	16	0	16	46	0	46	4	50	1	51	35967.648
41	11	0	11	17	0	17	13	1	14	42	3	45	0	45	0	45	34304.148
42	12	0	12	15	0	15	15	1	16	43	0	43	1	44	0	44	32935.301
43	14	0	14	16	0	16	13	2	15	45	0	45	3	48	1	49	35265.301
44	11	3	14	17	1	18	14	0	14	46	0	46	0	46	1	47	35411.5
45	12	0	12	14	1	15	13	1	14	41	0	41	1	42	4	46	33989.5
46	15	1	16	15	0	15	12	2	14	45	1	46	0	46	0	46	35448.199
47	12	1	13	16	0	16	16	2	18	47	1	48	2	50	3	53	35752.602
48	13	2	15	17	0	17	14	0	14	46	0	46	1	47	6	53	35366.148
49	14	0	14	16	0	16	15	3	18	48	0	48	2	50	4	54	36095.898
50	10	0	10	16	1	17	14	0	14	41	1	42	2	44	4	48	36874.949
51	12	0	12	17	0	17	12	0	12	41	2	43	1	44	0	44	37066.551
52	13	4	17	15	0	15	11	0	11	43	1	44	0	44	1	45	38854.699

Total supply chain cost (Tk)= 17,92,674

GRAPHICAL PRESENTATION

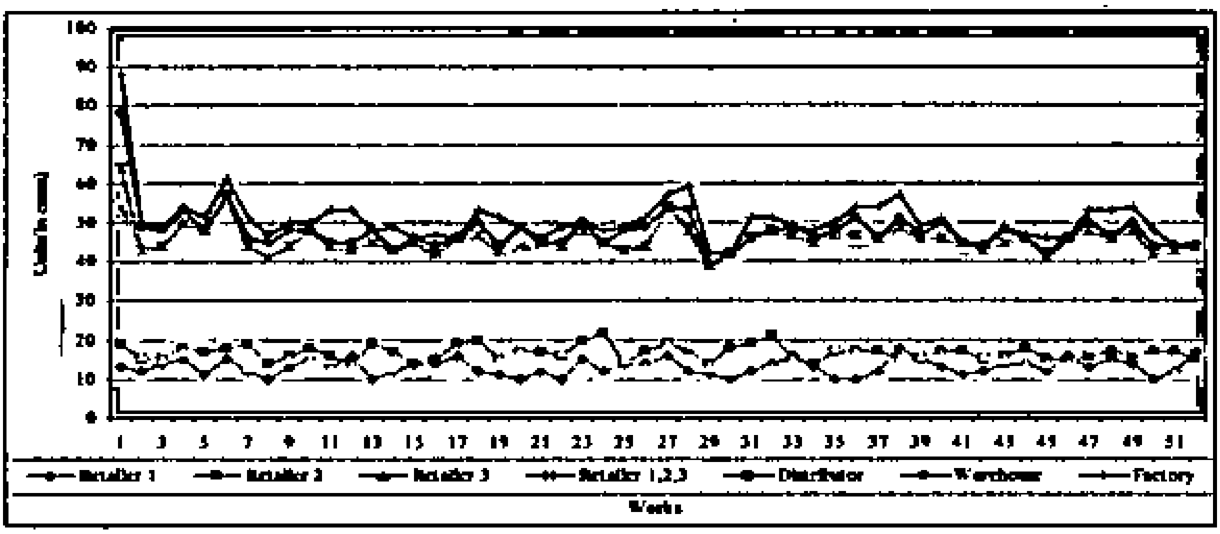

Figure: Graphical presentation of ordering policy for generation10000, population 40, cross over 0.5, mutation 0.5 for analysis 2