Impact of Supply Chain Strategies on Bullwhip Effect

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ABSTRACT

IMPACT OF SUPPLY CHAIN STRATEGIES ON BULLWHIP EFFECT

Changes of today's firm's competitiveness strategies from firms level to improved Supply Chain level causes increases in number and importance of Supply Chain studies in the literature. Variation between demand and orders is became the most important problem and most studied Supply Chain topic. This problem named in literature as Bullwhip Effect, is studied in this thesis with possible 11 factors effect on bullwhip. By using the improved Bullwhip Effect formula; lead time, review period, demand distribution, ordering cost, numbers of forecast periods are found as the factors which have significant effect on Bullwhip. In addition to this, for the use of similar Supply Chain researches, or real Supply Chain members, an improved spreadsheet simulation tool is prepared to test the proposed Supply Chain structures effects on different Supply Chain performance measures.

Keyword: Supply Chain, Bullwhip Effect, Spreadsheets, Simulation.

ÖZET

FARKLI TEDARİK ZİNCİRİ STRATEJİLERİNİN KAMÇI ETKİSİ ÜZERİNDEKİ SONUÇLARI

Günümüzde işletmelerin birbirleriyle olan rekabetinin, firmalar arası düzeyden güçlü ve gelişmiş tedarik zinciri düzeyine çıkarması, literatürdeki Tedarik Zinciri çalışmalarının önem kazanmasına ve artmasına sebep olmuştur. Talep ve siparişteki belirsizlik ve dalgalanmaların, tedarik ziniciri üzerindeki etkisi en büyük sorun ve en çok üzerinde çalışma yapılan konulardan biri olmuştur. Kamçı etkisi, olarak adlandırılan bu sorun ve bu etkiyi tetiklediği düşünülen 11 faktör, bu çalışmada incelenmiştir. Kamçı etkisi formülünün de geliştirilmesi sağlanarak, bekleme süresi, sipariş çevrim süresi, talep dağılımı, sipariş verme maliyeti, talep tahmin süresi gibi faktörlerin Kamçı etkisi üzerinde belirgin sonuçları olduğu tespit edilmiştir. Buna ek olarak, farklı tedarik zinciri yapılarının, performans ölçümlerine olan etkisinin incelenmesini sağlayan, elektronik tablolar yardımıyla hazırlanmış yeni bir simulasyon aracı, akademik veya endüstriyel çalışmaların kullanımına sunulmuştur.

Anahtar Kelimeler: Tedarik Zinciri*,* Kamçı Etkisi, Elektronik Tablolar, Benzetim.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

In today's global marketplace, competition between firms is not limited to brand names and products; the success of a firm depends on the true management of the Supply Chain members.

Companies work with several suppliers, starting from the ordering of raw material until converting this raw material into finished products and delivery of the products to customers. The coordination and management of information, material and money flow within a company and its suppliers is hard and complex process. Several problems occur related to delivery time, quality and quantity of products.

The problems between suppliers and company directly affect the final product's quality and the company's image. 'Supply Chain Management' is a term which aims to prevent possible Supply Chain problems and find solutions and make improvements for this chain.

Supply Chain Management defined as an integrated management of suppliers, companies and customers to provide in shortest time, products with highest quality and lowest cost.

The scope of the Supply Chain is very wide; it includes different research topics according to the problem. For example; for the decisions of suppliers selection, ‘Supplier Selection Methods’, location of suppliers, ‘Supply Chain Network’ are the new topics in the literature which is defined according to the increasing attention and importance of Supply Chain problems. Number of suppliers in the chain, information sharing strategies, and cost policies can also be other examples for Supply Chain research topics.

The most important and significant problem in the chain is related with the demand and orders. Because in any Supply Chain, even one stage Supply Chain there is a variation difference between orders and demand. It is proven in the literature that variation of orders increases as one move up in the chain and this is defined as ‘Bullwhip Effect’. This variation difference causes increasing ordering and inventory holding cost. In addition to this delivery time and order quantity problems causes a decrease in customer satisfaction with increase in backorder costs.

Several studies made for the causes and results of Bullwhip Effect. Some researchers tried to investigate factors causing Bullwhip Effect some of them tried to find solutions to reduce the adverse effect of bullwhip by using different methods; simulation and/or case studies.

This thesis aim is to determine the Impact of Supply Chain Strategies on Bullwhip Effect. In literature there are different researches related to Bullwhip Effect which increases day by day. But most of the studies are case studies and there can be a solution guideline only for similar cases defined in the research and not sufficient to make general result for the Bullwhip Effect.

In this study, firstly a new, improved simulation tool will be built. By this simulation tool any Supply Chain strategies will be tested, and tool can be downloaded and used by any Supply Chain member. Since it is modeled with Ms Excel, this is a user friendly simulation tool and not complex and costly as other simulation tools.

Second step is the determination of possible factors that can cause Bullwhip Effect. In literature there are similar studies deals with factors effect on bullwhip. But those studies limited with only three or four factors combination. In this thesis study, 11 factors, which are, demand forecasting technique, demand distribution type, ordering cost, holding cost, backorder cost, and demand mean, demand variance, number of forecast periods, lead time, review periods and service level. Effects on bullwhip will be detected according to two different ordering policies; lot for lot and standard out policies.

Review period is one of the most important factors but in literature generally it is assumed as 1 and not studied its effect on bullwhip. The reason for this is the defined Bullwhip Effect formula in the literature; it causes misleading results in different review periods. In this thesis Bullwhip Effect formula also improved to solve this problem.
Bullwhip Effect is the most important and common performance measure. But additionally to this, net stock amplification, holding, backorder, ordering and total cost are the other performance measures added to simulation tool to be able to simulate more real cases and have more accurate results.

Finally two different design analysis will be made to have valid and accurate results and comments for the impacts of different Supply Chain strategies on Bullwhip Effect for two different ordering polices.

As a conclusion, this thesis will provide a new simulation tool for Bullwhip Effect studies with an improved Bullwhip Effect formula. Design analysis will be made for all factors defined in literature and faced in real life to show their effects on bullwhip and make suggestion to reduce Bullwhip Effect in any Supply Chain.

The thesis will continue with a complete Supply Chain literature review, following with a Methodology chapter to explain simulation in detail, then in Design of Experiment Chapter simulation results will be analyzed, and design results and suggestion for the solution of Bullwhip Effect problem will be given in conclusion Chapter.

CHAPTER 2

LITERATURE REVIEW

Supply Chain Management is defined in the literature, as an integrated management policy of suppliers, companies and customers, to provide the right raw material, the right product, the right delivery method with the lowest cost and highest quality.

Beamon B.M. (1998) states that "A Supply Chain may be defined as an integrated process wherein suppliers, manufacturers, distributors, and retailers work together in an effort to: obtain raw materials, convert these raw materials into specified final products, and deliver these final products to retailers. This chain is traditionally characterized by a forward flow of materials and a backward flow of information**".**

Min and Zhou (2002) suggests two main business process in a Supply Chain to provide that material and information flow. The business processes are defined as material management and physical distribution. Material management refers to the inbound logistics such as production control, warehousing, shipping and transportation of finished products.

Physical distribution refers to outbound logistics that are pricing, promotional support, returned product handling and life cycle support. For a Supply Chain this combination of material management and physical distribution activities causes multiple business networks and relations instead of linear one to one business relationships.

The limits and contents of each Supply Chain's nonlinear relation network are not same for every Manufacturing or Service Company. For this reason, before modeling a Supply Chain, the first step that a model builder should do is defining the scope of Supply Chain model. As Min and Zhou (2002) states there is no systematic way of defining the scope of Supply Chain problem. But there are different guidelines in the literature. One of them is proposed by Stevens (1989). This guideline is consisting of three levels of decision hierarchy. First one is competitive strategy which includes location-allocation decisions, demand planning, distribution channel planning, strategic alliances, new product development, outsourcing, supplier selection, information technology selection, pricing, and network restructuring. Secondly tactical plans; includes inventory control, production/distribution coordination, order/freight consolidation, material handling, equipment selection, and layout design. Finally operational routines; that includes vehicle routing/scheduling, workforce scheduling, record keeping, and packaging

Another guideline to follow is suggested by Cooper et al. (1997b). The three structures of a Supply Chain network suggested is: (1) the type of a Supply Chain partnership which can be primary and secondary; (2) the structural dimensions of a Supply Chain network that can be horizontal and vertical; (3) the characteristics of process links among Supply Chain partners such as managed business process links (firm integrates a Supply Chain process with one or more customers/suppliers), monitored business process links (firm is involved in monitoring or auditing how the link is integrated and managed), not managed business process links (firm fully trusts its partners' ability to manage the process links and leaves the management responsibility up to them), and non-member business links (that are the ones between both partners and non-members of the company's Supply Chain).

Defining the scope of the Supply Chain model helps to construct the structure of the model. But to adopt the model more close to real life situations the decision variables, constraints and suitable performance measures should be added to the model according to defined Supply Chain structure.

Since the Supply Chain structure is not same for every company, the decision variables and constraints are not same too. But there are some common examples in the literature that can be applied to most of the Supply Chain Models.

Decision variables can be; location, allocation, network structuring, number of facilities and equipment, service sequence, volume, size of workforce, extent of outsourcing, production/distribution scheduling, number of echelons, plant product assignment, buyer supplier relationships and number of product types held in inventory.

Constraints of the Supply Chain model can include capacity, service compliance (e.g. delivery time windows manufacturing due dates, maximum holding time for backorders, number of driving hours for truck drivers), and extend of demand.

Beamon B.M. (1998) states that “Supply Chain performance measures are categorized as either qualitative or quantitative. For qualitative performance measures: there is no single direct numerical measurement and quantitative performance measures: may be directly described numerically”. The qualitative performance measures defined as Customer Satisfaction, Flexibility, Information and Material Flow Integration, Effective Risk Management and Supplier Performance**.** The quantitative performance measures are also divided into two categories according to measures based on cost and measures based on customer responsiveness. For first category Cost Minimization, Sales Maximization, Profit Maximization, Inventory Investment Minimization and Return on Investment Maximization are given. For the second category that the measures based on customer responsiveness, the performance measures can be Fill Rate Maximization, Product Lateness Minimization, Customer Response Time Minimization, Lead Time Minimization and Function Duplication Minimization.

In this section, scope of the Supply Chain is defined; the required decision variables, performance measures and constraints are also explained for any Supply Chain structure. Researchers are used, defined constraints, decision variables and performance measure as a guideline for their study. The important part is to modify and adopt the given information of literature to the studied Supply Chain model.

Supply Chains are modeled especially to investigate and solve possible problems in the chain. As a result of experiments made related to Supply Chain, researchers discovered a common problem for all Supply Chains. This common problem is the increase of demand order variability as one move up the Supply Chain. All studies concludes that the variation of demand and orders have important effects to Supply Chain performance measures. This problem named in the literature as "Bullwhip Effect".

The first researcher of Bullwhip Effect was Forrester (1958). He did not use term as "bullwhip" but he defined as "Demand Amplification" and shows that there is variation between customers demand and manufacturer orders. His valuable study encourages other researchers to make studies related to "Bullwhip Effect" to make improvements for Supply Chain by determining causes and solutions of this problem.

Bullwhip Effect is studied by several researchers. Some of them tried to show that bullwhip existence in every Supply Chain, and some of them tried to find possible causes and solutions of Bullwhip Effect.

Lee et all. (1997) shows that there are five main causes of the Bullwhip Effect: The uses of demand forecasting, supply shortages, lead times, batch ordering, and price variations.

There are different models and methods to show Bullwhip Effect. The most popular one is the "Beer Distribution Game". In this game, 4-stage Supply Chain, which consisting of a factory, a distributor, a wholesaler and a retailer is modeled. This game aim is to provide a simulation area for players, to show causes of Bullwhip Effect and see the results of proposed solutions to Supply Chain performance. Simchi-Levi et al. (2000) [24]. improved beer game in to a computerized version. Today, researchers can use any version of beer game such as manual or computerized also web-based versions (e.g. Machuca and Barajas 1997, Chen 1998).

Beer game is not only used as a Supply Chain simulation tool. It also helps researches to understand the concept of Supply Chain. Some of the researchers not used that beer game simulation. They generate their own simulation tool or use any other tools. But as a common point the other Supply Chain simulation tools or methods are based on beer game's Supply Chain model with modified or improved versions.

Every Supply Chain has different Bullwhip Effect causes and different solutions. But when literate reviewed, it can be seen that there are some common problems and common solutions for Bullwhip Effect. Only need in literature is a single study, which examines all proposed bullwhip causes with all suggested solution techniques.

Chen et al. (1998) quantify the Bullwhip Effect in a simple 2-stage Supply Chain, to determine the effect of forecasting, lead times and information. They conclude that with moving average forecasting technique longer lead times are increases Bullwhip Effect. And centralized customer information that means, all Supply Chain members can have same access to customer demand information, by this way Bullwhip Effect can not be eliminated but can be reduced.

Manyem et al. (1999) is another example of a Bullwhip Effect simulation with similar results. They discussed the factors that influence Bullwhip Effect and its impact on profitability by using Supply Chain simulation. Conclusions are same, centralized information sharing strategy, has positive effect on bullwhip and also shorter lead time gives better Bullwhip Effects measures.

Cantor (2008) made a laboratory beer game simulation. In this study students come to laboratory and plays beer game by this way researcher have a dynamic simulation environment to see the effect of demand model and lead time on bullwhip.

Literature of Bullwhip Effect is mainly consisting of studies deals with investigation of Bullwhip Effect causes or quantifying the determined factors effects on bullwhip. Lead time, information sharing strategies and ordering policies are the common factors of Bullwhip Effect. Demand forecasting technique, ordering decisions, review period, and cost structure are the other important factors that affect bullwhip. But there is no single study which shows and discusses all bullwhip causes and their effects under different Supply Chain strategies. And the other important point is that, researcher chooses one of them, either generating their own Supply Chain simulation tool, or use predetermined simulation tool and make experiment for their proposed solution by using that tool.
Supply Chain studies can be done with different methods. Most important part is the modeling the Supply Chain. Some examples for Supply Chain modeling for Bullwhip Effect are given. Most of them are used simulation method. But in addition to this, there are some other Supply Chain modeling approaches, which will be explained with details in the following section.

Beamon B.M. (1998) states that mainly there are four Supply Chain Modeling approaches which are; Deterministic Analytical Models, Stochastic Analytical Models, Economic Models and Simulation models. Beamon B.M (1998) states that first three models (Deterministic Analytical Models, Stochastic Analytical Models and Economic Models) are used to find best algorithms or heuristics mainly for manufacturing companies.

In general these models focus on some important parts of production as minimizing lead time (the amount of time between the placing of an order and the receipt of the goods ordered.), smoothing demand variances, and scheduling production. Simulation Models are used for both manufacturing companies and for the service industry. This model aim is to modeling real life situations in simulation module to identify the problems and find ways to fix these problems.

Min and Zhou (2002) modified this classification and divide Supply Chain models into four different classes. First one is deterministic (non-probabilistic); second one is stochastic (probabilistic); third one is hybrid; and the last one is IT-driven models. As seen here there are similarities between two classifications. But Min and Zhou (2002) explains their classification as; "Deterministic models assume that all the model parameters are known and fixed with certainty, whereas stochastic models take into account the uncertain and random parameters.

The categories of decision analysis and queuing models from stochastic models are excluded, because the literature indicates that Supply Chain models rarely used such techniques. Hybrid models have elements of both deterministic and stochastic models. These models include inventory-theoretic and simulation models that are capable of dealing with both certainty and uncertainty involving model parameters. Considering the proliferation of IT applications for Supply Chain modeling, we decided to add the category of IT-driven models to the taxonomy.

IT-driven models aim to integrate and coordinate various phases of Supply Chain planning on real-time basis using application software so that they can enhance visibility throughout the Supply Chain".

The difficult decision is to select the best modeling approach for a Supply Chain. But choosing the right modeling approach is not enough; researchers also need to modify this model according to defined performance measure, decision variables and constraints of Supply Chain. To improve the knowledge of modeling approaches in Supply Chain, the examples of past studies that researchers made using different modeling approaches will be explained.

- Deterministic modeling approach; Ishii (1988) determined the base stock levels and lead times associated with the lowest cost solution for an integrated Supply Chain on a finite horizon. Cohen and Moon (1990) developed a constrained optimization model, called PILOT, to investigate the effects of various parameters on Supply Chain cost, and consider the additional problem of determining which manufacturing facilities and distribution centers should be open. Nozick and Turnquist (2001) proposed an approximate inventory cost function and then embedded it into a fixed-charge facility location model. The fixed-charge facility location model was designed to consider a tradeoff between demand coverage and cost associated with the location of automobile distribution centers.

- Stochastic modeling approach; Cohen and Lee (1989) developed model for establishing a material requirements policy for all materials for every stage in the Supply Chain production system. They use four different cost-based sub-models which are; Material Control, Production Control, Warehouse and Distribution. Pyke and Cohen (1990), considered an integrated Supply Chain with one manufacturing facility, one warehouse, and one retailer, and consider multiple product types. This model yields the approximate economic reorder interval, replenishment batch sizes, and the order-up-to product levels for a particular Supply Chain network. Swaminathan and Tayur (1999) solved a so-called *vanilla box* problem where the inventories of semi-finished products were stored in vanilla boxes and then were assembled into final products after a customer actually ordered them further into the Supply Chain. Their model considered random customer orders.

- Hybrid modeling approach; Karmarkar and Patel (1977) used a decomposition approach to solve a single product, single period, multiple location inventory problems with stochastic demands and transshipment between locations. To consider interactions between inventory management and transportation modal choice. Cachon (1999) utilized a game theory to take into account an infinite horizon, stochastic demand inventory problem between one supplier and one retailer. In his game theory, Cachon (1999) considered the possibility of 'double marginalization' (profit sharing between the supplier and the retailer), buy-back contracts, and quantity discounts to develop the optimal joint inventory policy. Karabakal et al. (2000) used a combination of simulation and mixed-integer programming models to determine the number and location of automobile distribution and processing centers as well as the set of market areas covered by each distribution and processing center, while evaluating customer performance measures such as the ability of Supply Chains to deliver a customer's preferred vehicle within short time windows.

- IT-driven modeling approach; Camm et al. (1997) combined an integer

programming model involving the location of distribution centers and sourcing of multiple products with a GIS to develop a flexible decision support system (DSS). However, their model-based DSS did not include capacity constraints. Talluri (2000) proposed a goal programming model for an effective acquisition and justification of IT for a Supply Chain. The model could be useful in selecting the right ERP system that can consider system acquisition and maintenance costs, flexibility, execution accuracy, and compatibility.

- Simulation modeling approach: Towill (1992) [28] chooses simulation

techniques to evaluate the effects of various Supply Chain strategies on demand amplification. The just-in-time strategy and the echelon Removal strategy are observed to be the most effective in smoothing demand variations. Wikner, (1991) examines five Supply Chain improvement strategies, and then implements these strategies on a three-stage reference Supply Chain model.

Most effective improvement strategy is, improving the flow of information at all levels throughout the chain, and separating orders

In this thesis study simulation modeling approach is chosen. The reasons to select this method, its advantages and disadvantages will be explained in the following "methodology" section.

CHAPTER 3

METHODOLOGY

Supply Chain can be modeled with stochastic, hybrid, information technology (it)-driven or simulation modeling approaches. The type of modeling method should be chosen according to the defined problem and Supply Chain structure.

In this study, impact of Supply Chain strategies on Bullwhip Effect is examined. In addition to this, all different Supply Chain strategies effect on other performance measures such as net stock amplification and the total cost are mentioned as another discussion topic of this study.

The Supply Chain model should be capable enough to show the consequences of any increase or decrease of factors to performance measures. For this reason, most suitable modeling tool for this type of Supply Chain study is chosen as ‘simulation’. Details for simulation method and sample Supply Chain simulation studies are given to better explain the other reasons for selection of the simulation method.

Y. Chang et al. (2001) states that Supply Chain simulation “helps to understand the overall Supply Chain processes and characteristics by graphics/animation.

Supply Chain simulation is able to capture system dynamics: using probability distribution, user can model unexpected events in certain areas and understand the impact of these events on the Supply Chain.

It could dramatically minimize the risk of changes in planning process: By what-if simulation, user can test various alternatives before changing plan". In addition to these explanations, Enns (2003) defined the procedure for the Supply Chain modeling in six steps. The first step is to understand the system, then to design the scenario and data collection. Next target should be defined for each performance measure and the definition of termination condition. Finally the Supply Chain strategies should be evaluated.

Enns (2003) also suggested simulation models and said that; simulation models provide a chance to model, information and materials flow in addition to decision strategies. User can eliminate unnecessary constraints or make desired assumptions for Supply Chain model, so any level of detail can be removed or added to the study by the help of simulation.

There are different applications of Supply Chain simulation models most of them uses the procedure defined by Y. Chang et al. (2001) to model their Supply Chain structures. According to the selection of application type of the simulation, all studies are differs from each others; some of them used available simulation tools (e.g. Arena, spreadsheets) and some of them generated new simulation tools (test bed, tactical-supply chain management game, beer game).

For example G. Frizelle et al. (2002) made a simulation study on Supply Chain complexity in manufacturing industry using arena, excel and visual basic software. Sezen (2004) made simulation to solve inventory problems in Supply Chain by using excel spreadsheets.

The simulation tools are not limited by available software packages, some researchers generate their own simulation tools, for example; S.T. Enns et al. (2003) made a simulation test bed for production and Supply Chain modeling and J. Liu et al. (2004) demonstrated another Supply Chain simulation tool which is called easy-supply chain, and it can be used for different Supply Chain studies.

Harrell and Tumay (1994) classified simulation in two categories. First one is "methods for solution and evaluation". In this category what-if scenarios are tested by using spreadsheet, discrete event system or system dynamic simulations. Second category is "method for solution generation" which aims to find the best solution for a given objective. Classical optimization approaches such as linear and non-linear optimization and simulation optimizations are the examples for this category.

This thesis aim is to both solution evaluation and solution generation. As a solution evaluation, spreadsheet simulation is chosen for simulation tool to test different Supply Chain strategies. And for solution generation several factors are considered with two different levels each and the design of experiment is made to find best possible solution scenarios.

Lambrecht et al (2003) prepared a spreadsheet simulation tool to explore the Bullwhip Effect. As they said the aim of the study is to build up a spreadsheet application for the use of educational purposes. The original spreadsheet model can be seen in bullwhip explorer.xls file in CD.

The bullwhip explorer tool is built according to beer game structure. This was a two stage, single echelon Supply Chain structure. Demand comes from customers, and manufacturer produce desired product by ordering raw materials from suppliers, the ordering is reviewed every period which means review period is assumed as one for all chains.

There are two different parts in the bullwhip explorer tool. Input section and output section. User can select different input values such as mean demand, standard deviation, and lead time. Then calculations are made automatically according to predetermined excel formula for each value of the demand, receive and order amount. The advantage and importance of this tool is providing a chance to user to select desired forecasting technique, and ordering policies from different alternatives.

The performance measures defined in bullwhip explorer are Bullwhip Effect, net stock amplification, customer service level and fill rate. At each different run the performance measures takes different values according to defined input values.

In this study the bullwhip explorer spreadsheet simulation tool is selected. But this tool is not capable enough to make defined experiment and test different strategies. So, the most important part is the modification and adaptation of the selected tool, to be able to analyze the expected solution evaluation and the generation of defined problems.

The original bullwhip explorer tool is designed for 500 periods. For this study, 500 periods is not enough to have an accurate result from each simulation run; it should be extended to get more applicable results so simulation period is extended to 4120 and one click on simulation button is given twenty different simulation results for each factor values which were predetermined in input excel file.

The input values should be changed at each run of simulation to test their effects on performance measures. For this reason, a separate input excel file is prepared. In this file, all different eleven factors are defined, and each of them is listed with two different levels as high and low. All different factor combination is listed in input excel file are ready for the use of simulation tool. The other excel file used in simulation is prepared for demand structure. Demand values are taken from this file according to the defined input values in simulation tool.

In simulation file, modification and improvements are made to test effects of all factors with the shortest and reliable method by adding new macros to simulate button. So, when user made one click on simulate button, all different factors values are automatically written from defined files and for each single factor combination 20 different performance measures results are calculated.

At the same time average of 20 different results of each performance measures is recorded in corresponding factor combination row. This will prevent writing errors in each run and time loss for each simulation. All details and explanations for input values determination and simulation tool modifications are explained in the following section.

CHAPTER 4

DESIGN OF EXPERIMENT

Bullwhip Explorer spreadsheet simulation tool is selected to test impact of Supply Chain strategies on Bullwhip Effect. In this chapter, the construction of Supply Chain model and modification of that Bullwhip Explorer simulation tool is explained. Firstly, the Supply Chain structure is defined, and then input variables selection definitions will be given, also the forecasting techniques and ordering policies are explained in details. In the last section, performance measures and their formulas are illustrated to provide full knowledge of simulation environment before explaining the results of each run.

Supply Chain structure consists of one retailer, one manufacturer and customer. This is single-item, 2-stage, and single-echelon Supply Chain similar to other Supply Chain studies. As shown in figure, initially, demand comes from customers, retailer provide desired demand if available from the inventory, otherwise backlogged and place order to supplier, after order received customer demand is satisfied.

Figure 4.1: Supply Chain Structure

4.1 Input Module

The inputs are the most important parts of the simulation tool. Because all selected factors are defined here to test their effects on performance measures. As mentioned before there are eleven different factors. These are; forecasting technique, demand distributions, ordering cost, backorder cost, holding cost, demand mean, variance, number of forecast periods, lead time and finally service levels. All these factors are determined as a result of hard and detailed research on Supply Chain literature. And it is quite clear that, this study becomes the unique study in literature which combines all defined and undefined factors in a single study to test their effects on Supply Chain performance.

1. Define a demand pattern: uniform   **2. Select test number:** 512

2. Define the demand parameters:

1	128	M-N
129	256	M-U
257	384	E-N
385	512	E-U

mean demand	$\overline{D}$	25,00
autoregressive coefficien	ρ	0
variance of error term	σ^2_ε	5,00
variance demand	σ^2_D	5,00

unit holding cost per period	Ch	1,00
unit backlog cost per period	Cb	1,00
unit ordering cost per period	Co	0,00
safety stock	SS	7,36

physical lead time	Tp	1
review period	Rp	1
total lead time	L	2
lead time demand	$\overline{D}_L$	50,00
stddev lead time demand	σ_L	3,16
safety factor	z	2,33

3. Define a demand forecasting technique:

EXPONENTIAL SMOOTHING

4. Define the demand forecasting parameters:

number of periods	Tm	15
smoothing parameter	α	0,125
signaling factor	χ	1,00

Figure 4.1.1: Spreadsheet simulation input module

As shown in figure 4.1.1. all factors values are defined in input section of simulation tool. For example first the demand parameter value needs to be entered (i.e. Mean Demand). It is the average demand represented as $\overline{D}$.

In original bullwhip explorer tool, the mean demand value is taken as a constant value. But, in this study since it is one of the factors which could have an impact on Bullwhip Effect, two different, mean demand values are chosen to show it's high and low conditions. 10 represent the low and 25 represents the high levels of this factor. Following input value and factor is the demand variance. It is represented as $\sigma^2{}_D$ and calculated by the formula shown below;

$\sigma_D^2 = \sigma^2{}_{\square} / (1 - \rho^2)$

ρ: autoregressive coefficient

In bullwhip explorer it is chosen as a constant value. In this study, 1 show low and 5 shows the high level of this factor.

In bullwhip explorer file demand type can be chosen as independently and identically distributed (IID) or AR demand types. But here it is assumed as independent and identically distributed demand. But it is known that for independent and identically distributed demand autoregressive coefficient ρ is and variance of error term $\sigma^2{}_{\square}$ are equal to zero

In this study instead of demand type, demand distribution is selected as a factor which can have an impact on Bullwhip Effect. So, two different demand distributions; normal and uniform are tested to see their effects on Supply Chain performance.

In bullwhip explorer the demand values are randomly generated according to demand type and each different click on simulate button will be result in different random demand values for each 500 periods.

The random number generation should be made according to different demand distributions and different demand mean and variances. Also for each different click on simulate button; demand pattern should not be changed while the other input values were same.

By this way, all factors effect is tested in the same simulation environment. For this reason a separate demand excel file is prepared to be ready to use in simulation tool. In demand excel file, there are eight different random demand numbers generation list for each different demand distribution; normal and uniform and for each high and low values of mean and variance. To have valid results, all these eight demand values are tested using ARENA Input analyzer. Input analyzer result is shown in appendix in figures 1-8. For example random demand number generated with normal distribution with mean 10 and variance 1 tested in input analyzer and it also resulted as normal distribution with mean 10 and variance 1.

To sum up, in simulation tool when demand mean and variance is changed according to the factor combinations in input excel file, suitable random demand values are taken from that excel file and when a new click made on simulate button, these demand values will not be changed while the mean variance and demand distribution were same.
The other input value and factor is physical lead time (T_p). It is the lead time caused by transportation lag or any other material delivery delays. In bullwhip explorer user can choose any constant value to the simulation tool. But increase and decrease of lead time directly affects Bullwhip Effect. Several studies made to see the effect of lead time on Bullwhip Effect. To compare with existing literature, in this study lead time is one of the factors and it is values are determined as 1 for low and 5 for high level of this factor.

Review period R_p is the position which shows the time to review inventory position. In bullwhip explorer it is assumed as 1 which means inventory position is reviewed every period. Also most of the other Supply Chain studies assumed the review period is one.

The reason for that can be the simplification of the study and usage of existing Bullwhip Effect formula with same number of orders and demand in each period. Because when review period is different from one, in some period orders can be zero even there is demand. And different data series for demand and orders values could cause some mistakes or not correct variance of orders and demand comparison for Bullwhip Effect.

But in this study, review period is selected as an important factor which can affect Bullwhip Effect and 1 and 5 is selected for its low and high levels. The existing Bullwhip Effect formula in literature is not given correct result when review period is high. For this reason the known Bullwhip Effect formula is needs to be improved in this study to be able to use in every different situation and be more close to real life by different review periods. Details for Bullwhip Effect formula will be explained in performance measure section.

The input section is continued with total lead time (L),

$L = R_p + T_p$

Average lead time demand (DL) and standard deviation (σ_L) are calculated by the following formulas;

$DL = L * D$

$\sigma_L = \sqrt{L * \sigma_D^2}$

Another important input is safety stock which is the minimum amount that should be held in inventory which and is calculated by the formula shown below. It has an important role for the decision of ordering amount and time.

$$\text{Safety stock} = ss = z * \sigma_{Rp+Tp}$$

In safety stock calculation safety factor (z) is the key element. For this reason, safety factor should be one of the factors needed to test its impact on Bullwhip Effect. Two different service levels are selected as 80% and 90%, so their corresponding z values, 0.842 and 2.327 are defined as low and high levels of safety factor.

There are different forecasting techniques for future demand calculations. Since demand is an important element of Supply Chain, the demand forecasting technique could be effective for Bullwhip Effect. In literature many similar studies made discussions for the demand forecasting effects on bullwhip. To be consistent with literature, in this study moving average and exponential smoothing are selected as two different types of demand forecasting techniques.

Demand forecasting techniques are determined. Now, the forecasting parameters should be defined. Most common elements of forecasting are number of periods (N) for moving average and smoothing parameter (α) for exponential soothing. The high and low level for number of period is determined as 7 and 15.

As seen in the following formula, smoothing parameter calculation is done by using number of forecast periods value, for this reason instead of taking in to account as two different forecasting parameters, only number of forecast period is selected as factor which can affect Supply Chain.

$$\alpha = \frac{2}{N+1}$$

Costs are the other important input values for this simulation model. Most of the previous Bullwhip Effect studies not taken into account the cost structure in to their models.

But in this thesis, three different cost values are selected and two different values for each of them are determined to see their impacts on performance measures.

The cost structure components are explained in the following definitions;

- *Holding (or carrying) costs*: Costs for capital, taxes, insurance, etc. (Dealing with storage and handling)
    - low level: 0,1 and high level: 1 TL/unit-period

- *Ordering costs (services & manufacturing*): Costs of someone placing an order, etc.
    - low level: 0,1 and high level: 1 TL/unit-period

- *Shortage (backordering) costs*: Costs of cancel or postpone an order, customer goodwill, etc.
    - low level: 10 and high level: 100 TL/order

4.2 Calculation Module

5. Click the button to run the model

SIMULATE

period	receive	demand	NS	WIP	demand forecast	OUT-level	order LFL	holding costs	ordering costs	backorder costs
			20		25,00		25			
1	25	17	28	25	23,97	55	2	28,25	0,00	0,00
2	25	21	33	2	23,54	54	20	32,74	0,00	0,00
3	2	33	2	20	24,70	57	35	1,92	0,00	0,00
4	20	22	0	35	24,37	56	21	0,00	0,00	0,15
5	35	31	4	21	25,15	58	32	4,22	0,00	0,00
6	21	17	8	32	24,11	56	15	8,38	0,00	0,00
7	32	20	20	15	23,65	55	20	19,98	0,00	0,00
8	15	22	13	20	23,46	54	21	12,80	0,00	0,00
9	20	28	5	21	24,00	55	29	5,03	0,00	0,00

Figure 4.2.1: Spreadsheet Simulation Calculation Module

Each customer demand is taken in constant time intervals. This time intervals are shown as periods. In original Bullwhip explorer tool there are 500 periods. Initially by using the original Bullwhip explorer spreadsheet, bullwhip for each time period is calculated and as shown below; bullwhip graph is drawn for 500 periods to observe warm-up period.

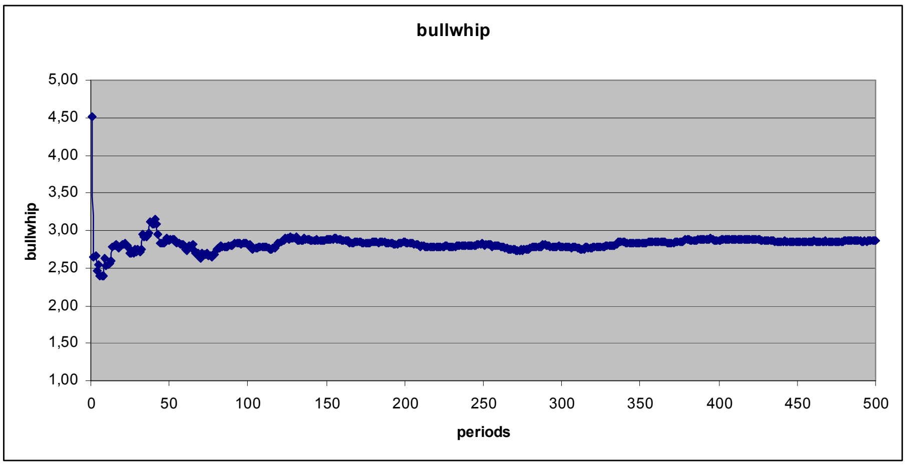

Figure 4.2.2: Bullwhip Effect Graph

As seen in graph after 100 periods, the bullwhip takes more similar values. Because of this, in improved bullwhip explorer, spreadsheet is designed for 4165 periods, which means; there are 20 different simulation runs with each have 200 period lengths, and first 100 period is not taken in to account for each performance measure calculation.

The second value in spreadsheet simulation is receive. Receive shows the number of orders arrived to retailer. When the inventory position is not sufficient, new orders placed to the manufacturer, and then these orders are received by retailer to satisfy lead time demand. For example if total lead time unit was 3, receive in period 6 is equals to, the number of orders in period 3.

Demand is the random customer demand values which are assumed to be uniform or normally distributed with mean demand and variance demand as defined in input section.

NS is the net stock quantity in each period. Net stock formula is given below. According to the formula, net stock of sixth period is equals to net stock of fifth period plus order placed in third period minus sixth period's customer demand.

$$NS_t = NS_{t-1} + O_{t-(Tp+1)} - D_t$$

WIPt is the work in process inventory in period t. It equals to the work in process inventory of previous period plus orders placed previous period minus total lead time periods ago order value.

$$WIP_t = WIP_{t-1} + O_{t-1} - O_{t-(Tp+1)}$$

Demand forecast can be done by using different forecasting techniques. In this study, as explained in previous section moving average and exponential smoothing techniques are used. In input part user can select desired forecasting technique from the list. Two forecasting methods and demand forecast calculations are explained in the following section.

Moving average method; demand forecast is measured by taking the average of determined past periods (Tm) actual demand values. Each next forecast removes demand in the oldest period and replaces it with the demand in the most recent period; so, the data in the calculation "moves" over time.

$$\hat{D}_t = \left(\sum_{i=0}^{Tm-i} D_{t-i} \right) / T_m$$

Exponential smoothing is the other forecasting technique used in this study. In this method demand forecast is calculated by using forecast error to correct the previous smoothed value (α).

$$\hat{D}_t = \hat{D}_{t-1} + \alpha(D_t - \hat{D}_{t-1})$$

Inventory replenishment rule applied in this study is the period review system. The other type of replenishment rule is fixed order quantity system. In fixed order quantity model, quantity of ordered product is same but order time intervals are varies. But in periodic order systems, the orders are made in specified time intervals with different order amounts. As mentioned before, in periodic order system order quantities are change in each period.

The calculation of order period can be done with different ordering policies. In literature there are different researchers made studies for effect of inventory policies on Bullwhip Effect. In this study it is decided to run the simulation model according to two different inventory policies to observe their effect on Supply Chain performance measures.

First chosen inventory policy is lot for lot policy since it is most widely used in real life and the second one is standard periodic review order-up-to policy since it is most widely used in Bullwhip Effect literature.

Lot for lot policy is most common in industries because of its practical and easy application. If the forecasted demand (F_t) at the beginning of an order period is k with a lead time of τ periods the order amount in lot for lot ordering policy is calculated by the following formula:

Every k-period's lot for lot order size = $\sum_{i=1}^{k} F_{t+\tau+i}$

Second ordering policy is standard order up to level policy. In standard periodic review order-up-to policy, the inventory position IPt is calculated at the end of every review period Rp and compared with an order-up-to (OUT) level S_t. IP_t is the addition of the net stock NS_t and the inventory on order WIP_t.

The OUT level S_t is calculated by summation of the forecasted average lead time demand and a safety stock. Forecasted lead time demand is the multiplication of total lead time by forecasted demand (by using moving average or exponential smoothing). The OUT level (St) is calculated with the following formula.

$$S_t = \hat{D}_L^t + \text{Safety Stock}$$

$\hat{D}_L^t$: forecasted average lead time demand

Out level shows the target inventory level. For this reason in each review period new order should made to raise the inventory quantity to out-level. Order amount is calculated by the following formula; which shows the difference of out level from inventory position.

$$O_t = S_t - (NS_t + WIP_t)$$

The last calculations in simulation are done to calculate cost structure. There are three different cost values. Inventory holding cost (C_t^h), ordering cost (C_t^o) and backorder costs (C_t^b). The calculation of each cost is made according to the following formulas.

Holding cost, where $NS_t >= 0$

$$C_t^h = C_h * NS_t$$

Backorder cost, where $NS_t <= 0$

$$C_t^b = C_b * |NS_t|$$

Ordering cost, where $O_t \neq 0$

$$C_t^o = C_o * 1$$

The all input values and calculations are defined with their formulas. The last part of simulation is the calculation of performance measures with given input values. The performance measures and their formulas are explained in next section.

4.3 Output Module:

In original bullwhip explorer there are only four different performance measures; bullwhip, net stock amplification, customer service level and fill rate. But in this study, different performance measures are used to have more effective results and recommendation for each factor's effect.

Bullwhip is the main performance measure in simulation. It is calculated by the following formula, which says division of variance of orders to variance of demand. As

Bullwhip measurement equal to one means there is no variance amplification, demand variance and order variances are same. But if bullwhip is bigger than one, it means that Bullwhip Effect is present and solution to reduce them should be investigated. In literature the bullwhip is defined as in the formula shown below;

$$\text{Bullwhip} = \frac{\sigma^2_{orders}}{\sigma^2_{demand}}$$

But as explained in input section this formula is not applicable when review periods is different form 1. Because in some periods there could be no orders so, the number of orders and demand would not be in same amount and this would cause wrong variance comparison. For this reason Bullwhip Effect formula is improved to be ready to use in all different review period situations.

The improved Bullwhip Effect formula is generated by adapting coefficient of variation formula. It represents the ratio of the standard deviation to the mean, and it is a useful statistic for comparing the degree of variation from one data series to another, even if the units or means are drastically different from each other.

$$\text{Coefficient of Variation } = \frac{\sigma}{\mu}$$

So, the improved Bullwhip Effect formula is generated as shown in the following formula:

$$\text{Bullwhip Effect} = \frac{\sigma_{orders} / \mu_{orders}}{\sigma_{demand} / \mu_{demand}}$$

Net stock amplification is the second performance measure which also used in original bullwhip explorer simulation. It shows the increase in inventory variance, and gives an idea about customer service level, by illustrating if there is a need for more safety stock. The original formula is shown below;

$$\text{NSAmp} = \frac{\sigma^2_{netstock}}{\sigma^2_{demand}}$$

Similar to Bullwhip Effect the net stock amplification formula also improved to get valid results in different input values, but as a remark net stock is used as a performance measure in spreadsheet simulation but the analysis design for the factors effect on net stock amplification is not discussed in this study. The improved formula which used in simulation is shown below;

$$\text{NSAmp} = \frac{\sigma_{netstock} / \mu_{netstock}}{\sigma_{demand} / \mu_{demand}}$$

Final output values are calculated for cost structure. These can be calculated as;

Total holding cost = summation of all holding cost for each 200 periods.

Total backorder cost = summation of all backorder cost for each 200 periods.

Total ordering cost = summation of all ordering cost for each 200 periods.

Total cost = summation of all holding, ordering and backorder cost for each 200 periods.

In this section, all input values and calculations for simulation model are explained in details. The simulation spreadsheet is finalized according to these defined values. The input excel file for lot for lot and for standard out policy are given in CD, in this file all factor combinations are listed with their corresponding output values, also demand values are given in CD with two separate excel file; one for lot for lot and one for standard out policy. Finally Bullwhip Effect simulation spreadsheets are prepared and simulation for standard out policy is shown in figure 9 and spreadsheet simulation for lot for lot for is shown in figure 13.

When user open related excel files and run the simulation, all factor combinations are automatically written to the simulation model and related input and output values are respectively recorded to predetermined file destinations. As a result of this automated simulation study all factor combinations results can be calculated in 15-20 minutes.

All input values and output values are ready, next step should be the analysis and explanation of these results. Minitab statistical analysis software is used to make these analyses and to get valid results for the effects of factors on Supply Chain. Details and explanation of the analysis are explained in the following chapter.

CHAPTER 5

EXPERIMENTAL ANALYSIS

Minitab is statistical analysis software for the use of academic or business statistical researches. In this thesis the aim is the identification of eleven different factors effect on Supply Chain performance measure such as Bullwhip Effect.

There are two different simulation models, one of them is for lot for lot and the other one is for standard out policy. Their analyses are made separately but the same design of experiment is used since the cause affect structure is the same for both models.

Eleven different factors impact on Bullwhip Effect is analyzed using general full factorial design of experiments method. First the levels of each factor is defined, all factors have two levels in this study. Then the design is prepared for 4 replicate.

Replication number should be selected at least two to be able to estimate interaction effects, therefore it is selected as 4, for this study. Then, Minitab is resulted with 8192 rows for each different factor combinations.

The desired response value should be written for each row. For this reason each simulation model is run for 8 times, and average of twenty output values for each single simulation is recorded in different excel files, so 8192 different performance measure for each factor combinations of simulation models are prepared for the use of general full factorial analysis.

Figure 10, 11 and 12 shows the Minitab results for standard out policy and figure 14, 15 and 16 shows the Minitab results for lot for lot policy. When pre-calculated bullwhip values are entered to Minitab worksheet then, analyze factorial design button is chosen to see these results of the analysis. To better explain the results of defined analysis methods; additional graphs are selected in Minitab.

In this study, for the analysis of each simulation models with general full factorial design; analysis of variance, normal plot, main effects plot, interaction plot, pareto chart and normal effects plots are selected to better explain the results of the analysis

In the following section, effects of all factors on Bullwhip Effect for standard out policy and for lot for lot policy are explained according to general full factorial and ANOVA results in addition to the demonstration of related graphs.

The eleven different factors with their two different levels are summarized in the following table to provide more clear identification of the analysis.

1	**forecasting technique**	*low level*	*moving average*
		high level	exponential smoothing
2	**demand distribution**	*low level*	*normal*
		high level	uniform
3	**ordering cost**	*low level*	*10 TL/order*
		high level	100 TL/order
4	**holding cost**	*low level*	*0.1 TL/unit-period*
		high level	1 TL/unit-period
5	**backorder cost**	*low level*	*0.1 TL/unit-period*
		high level	1 TL/unit-period
6	**demand mean**	*low level*	*10*
		high level	25
7	**demand variance**	*low level*	*1*
		high level	5
8	**number of forecast periods**	*low level*	*7*
		high level	15
9	**review periods**	*low level*	*1*
		high level	5
10	**lead time**	*low level*	*1*
		high level	5
11	**service level**	*low level*	*0.842*
		high level	2.327

Table 5.1: Factors for standard out policy and lot for lot policy

5.1 Analysis for Standard Out Policy:

The experiment is designed for 11 factors with two levels. The experiment is handled with general full factorial design. Before explaining the result, the model adequacy is checked by the following statistical analysis.

Initially normality plot of residuals is drawn to test whether the normality assumptions are satisfied or not. (Douglas, 2005)

And as seen in the following graph, the response values are on the normal line, which means the normality assumptions are satisfied.

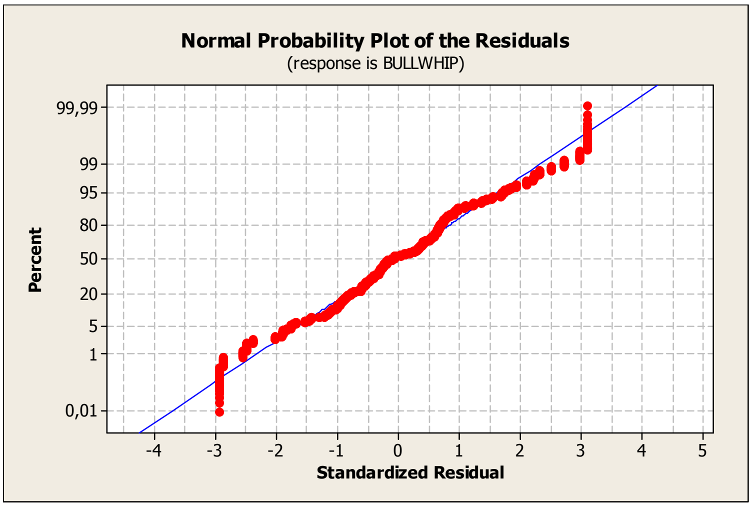

Figure 5.1.1: Normal Probability Plot for standard out policy

The other assumption is related with the variances. To test this assumption, the residual versus fitted values graph is selected, and as seen below, the graph shows that the variance is not following any known specific pattern.

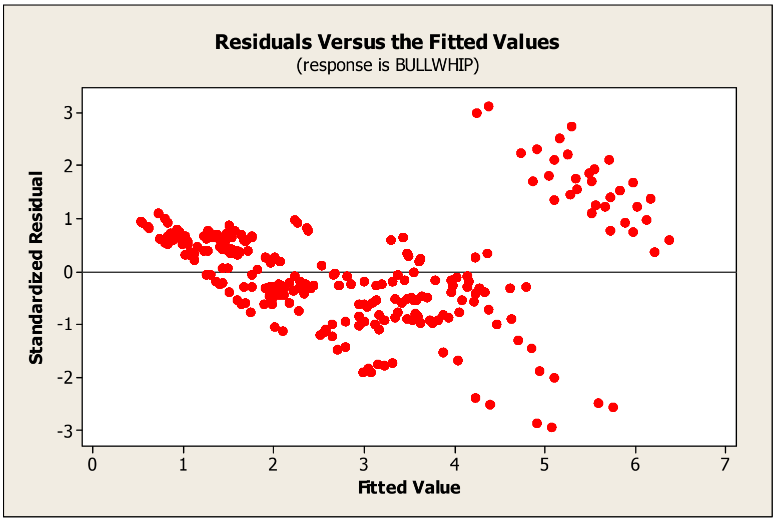

Figure 5.1.2: Residual plot for standard out policy

The null hypothesis for this experiment defined as; the factors have no significant effect on Bullwhip Effect. And according to ANOVA results, if the p-values are lower than the 0.05(alpha), reject the null hypothesis and say that the factors have significant effect on the Bullwhip Effect.

Finally ANOVA is created to test the hypothesis and to make analysis for factors impacts on Bullwhip Effect. As seen in the following Anova results we reject the null hypothesis and conclude that, demand distribution, ordering cost, demand mean, demand variance, number of forecast periods, review period, lead time and safety factor has significant effect on Bullwhip Effect. Because of their p values are smaller than 0.05. But demand forecasting technique, holding and backorder costs have no significant effect on Bullwhip Effect with their higher p values than 0,05.

Source	**p**
Demand forecast	1.000
Demand distribution	0.000
Ordering cost	0.000
Holding cost	1.000
Backorder cost	1.000
Demand mean	0.000
Demand variances	0.000
Number of periods	0.000
Review period	0.000
Lead time	0.000
Service level	0.020

Table 5.1.1: Analysis of Variance for BULLWHIP with Standard out policy

ANOVA demonstrated that 9 factors have significant effect on Bullwhip Effect for the standard out model.

To better explain the factors effect main effect plot is drawn. Graph shows each factors effect, where 1 represent the low and 2 represent their high levels. For example when lead time is higher the bullwhip value will be higher.

But for demand variance, the bullwhip will be decrease when the variance of demand increases. All factors results can be easily seen from the graph shown below.

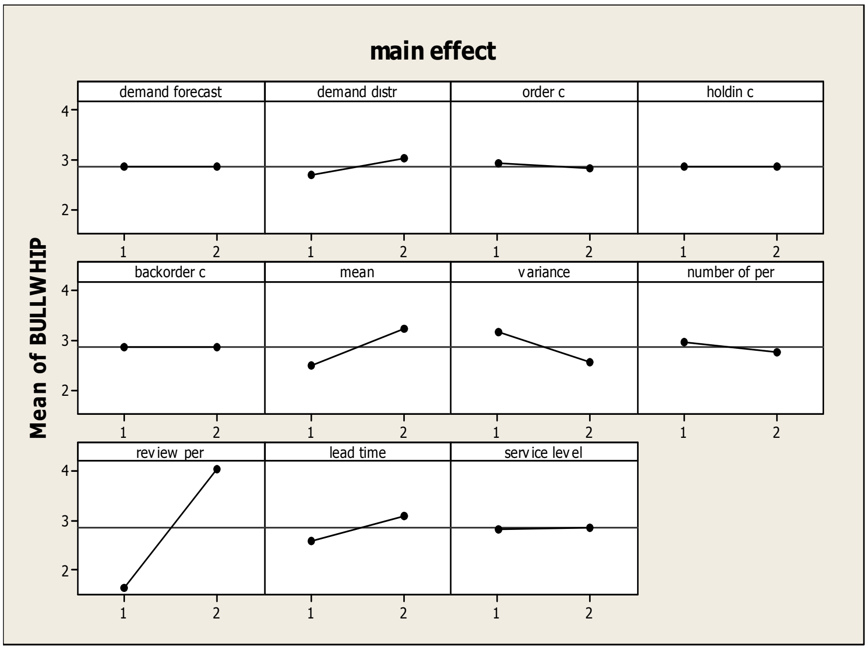

Figure 5.1.3: Main effects plot for standard out policy

The model adequacy is checked, significant factors are defined and their effects on bullwhip are also explained. In addition to this interaction plot can be used to analyze factor interaction effect and shown in appendix in figure 17 and 18. Finally the Pareto chart is given to show which factor has more significant effect on bullwhip.

As shown in the following chart, the review period is the most important factor for Bullwhip Effect. Second one is the demand mean. Third one is the interaction of the first two factors.

Then order cost and demand variance interaction show more significant effect than others. It is important to underline that some factors have more significant effect when they interact with other factor.

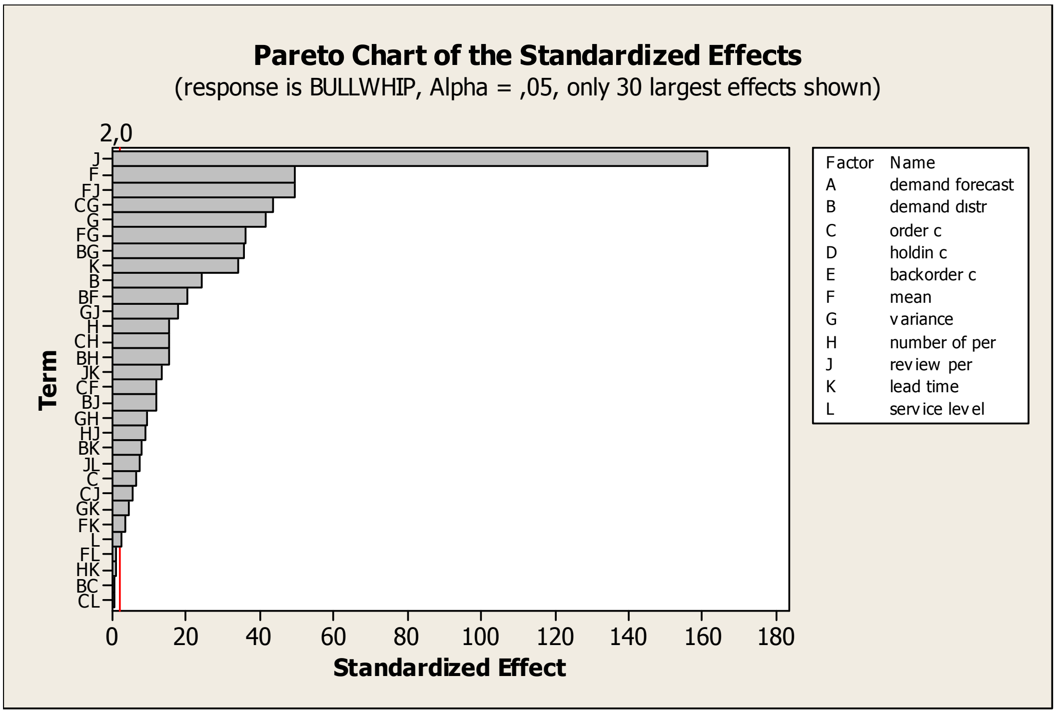

Figure 5.1.4: Pareto chart for standard out policy

5.2 Analysis Results for Lot for Lot Policy:

The design of the experiment is same as standard out policy. But the model adequacy needed to be checked also for this model. As seen in the following graph, the response values are on the normal line, and shows that the normality assumptions are satisfied.

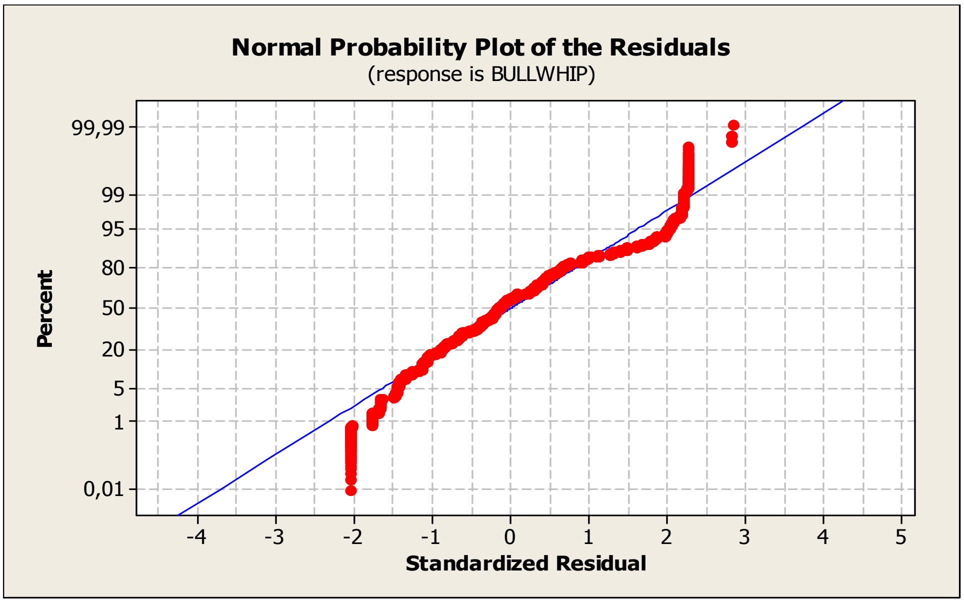

Figure 5.2.1: Normal Probability Plot for lot for lot policy

The following graphs show that the variance does not follow any known specific pattern.

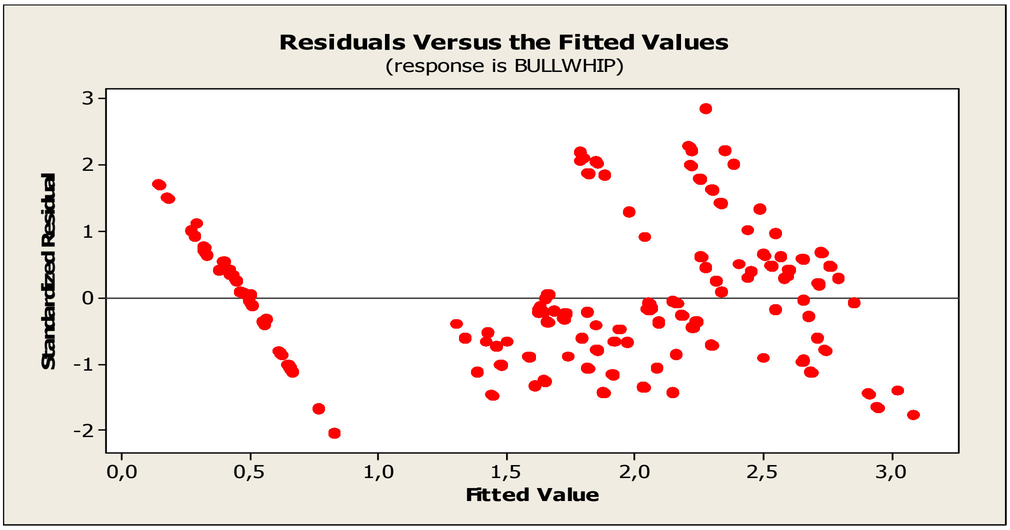

Figure 5.2.2: Residuals Plot for lot for lot policy

The general full factorial design with two level 11 factors is made same as standard out model. The null hypothesis is also same with previous model, the factors have no significant effect on Bullwhip Effect and if the p-values are lower than the 0.05(alpha) , reject the null hypothesis and say that the factors have significant effect on Bullwhip Effect.

To test the hypothesis following ANOVA is done. And as seen in the following ANOVA results, forecasting technique, holding cost, backorder cost and safety factor have no significant effect on bullwhip with high p values.

The other 7 factors have significant effect on bullwhip. Their effects details are explained in the following section.

Source	p
Demand forecast	0.979
Demand distribution	0.000
Ordering cost	0.000
Holding cost	0.979
Backorder cost	0.979
Demand mean	0.000
Demand variances	0.000
Number of periods	0.000
Review period	0.000
Lead time	0.000
Service level	0.979

Table 5.2.1: Analysis of Variance for BULLWHIP with Lot for lot policy

The following main effect plot is drawn to have an idea abut significant factors effect. It is shown in the graph that, when review period, lead time and demand mean increase the bullwhip value also increases. In addition to this, when demand is uniformly distributed or variance is high the bullwhip is decreases. Also interaction plots are provided in appendix in figure 19 and 20 to show the interaction factor effects on bullwhip.

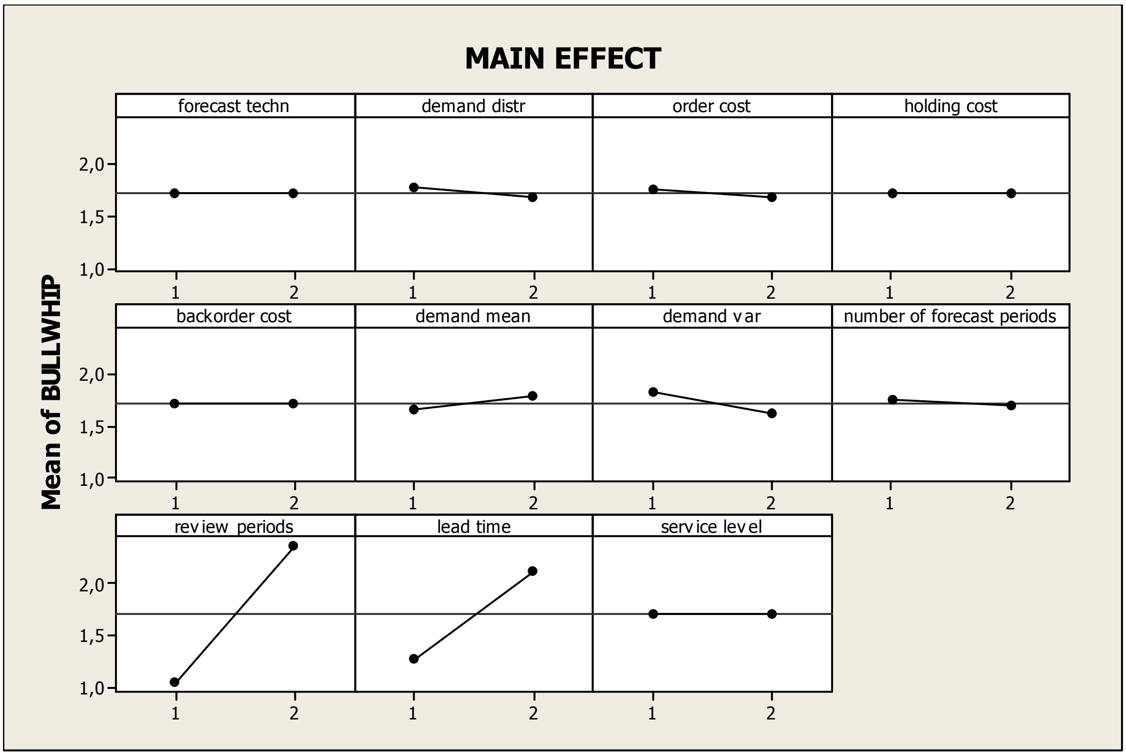

Figure 5.2.3: Main effects Plot for lot for lot policy

Pareto charts is again used to show which factor has most significant effect on bullwhip. As seen below, similar to standard our model, the review period is the most significant factor for bullwhip. But different form the standard out model, lead time has more significant effect on bullwhip in lot for lot model. Detailed discussion and conclusions of theses two model analyses is done in the conclusion section. For further information related to the design model; the complete form of Anova tables and additional design plots are also available as experimental design files in soft copy.

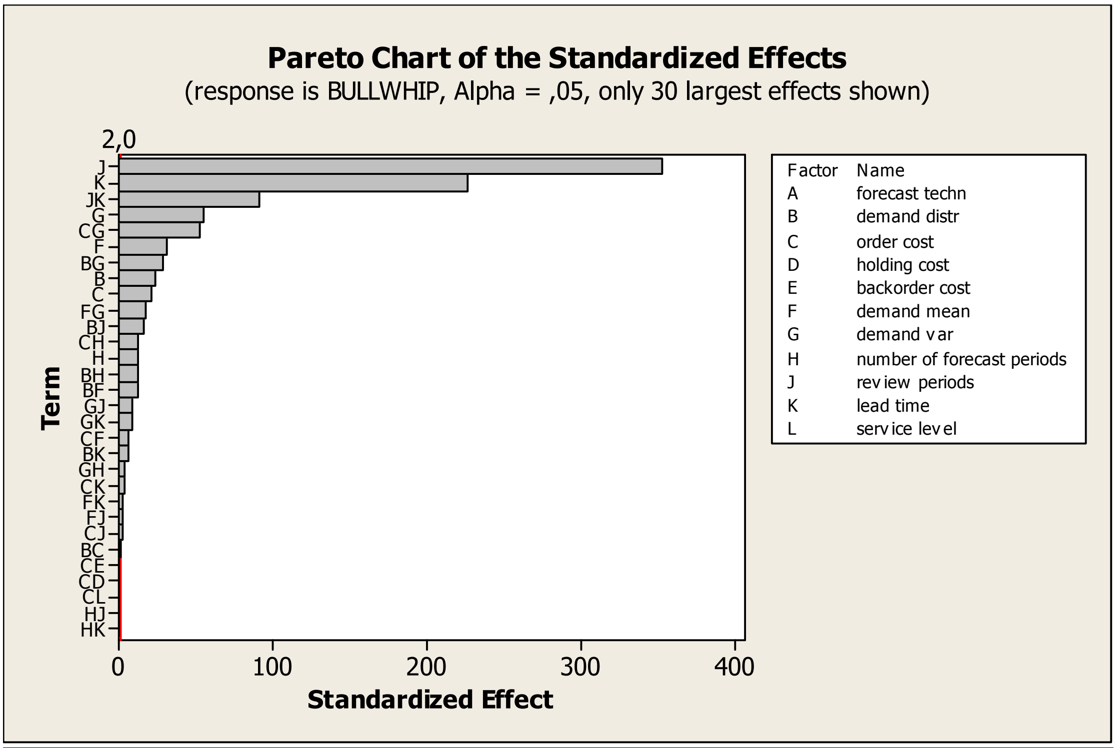

Figure 5.2.4: Pareto Chart for lot for lot policy

CHAPTER 6

CONCLUSION

The aim of this thesis was the investigation of different Supply Chain strategies on Bullwhip Effect. In literature there are similar studies related to Bullwhip Effect. Different from other studies, this thesis combined and analyzed all factors effects on Bullwhip.

The first important decision was related to the selection of factors. Hence, detailed literature survey is made in addition to real case observations. According to this survey, eleven factors are determined, and each factor is tested with its two different levels. First factor is selected as demand forecasting, and two different forecasting techniques; moving average and exponential smoothing is tested for each Supply Chain strategies.

Second factor was related to demand distribution; normal and uniform distribution is chosen to test this factor. Also, demand mean, demand variance, ordering, holding and backorder costs, number of forecast periods, lead time, review period and service level are the other factors and each of them has two different levels defined as high and low.

The last but most important factor is the ordering policy. Decision for two different types of ordering policy was another hard topic. Standard out policy selected, because of

it is most used ordering policy in Bullwhip Effect literature and Lot for lot ordering policy is selected since it is most widely used ordering policy in real cases.
As a result of 11 factors and two different levels for each of them, there are 2048 different factor combinations. In addition to this, all of them should be tested with two different ordering policies. To sum up, there are 2048 different Supply Chain strategies for standard out policy and 2048 strategies for lot for lot policy to test the impact on Bullwhip Effect.

It's obvious that the scope of this study is extensive. The most suitable methodology for this type of research as discussed in literature is Simulation technique. But none of the available simulation tools were suitable for this type of research. Therefore, another step of this study was the generation of a new Supply Chain simulation tool.

New simulation tool is designed with Ms Excel spreadsheets with the use of Macros. The tool can be downloaded and used for any type of Supply Chain research and/or industrial studies. To make more useful and accurate simulation tool, in addition to Bullwhip Effect, other performance measures, such as; net stock amplification, ordering, holding, backorder and total costs are also added as other output modules of the simulation. Additionally, this tool is user friendly and can be easily modified for different type of Supply Chain structures.

As said in the beginning the aim of this thesis is to test the factors effect on bullwhip. So, the quantification of the Bullwhip Effect was very important. But while making simulation for different review periods, it was observed that formula gives misleading results.

Because in literature Bullwhip Effect defined as, the rate of variance of orders to variance of demand. So, in different review periods, demand occurs in each period but orders are not same in each period. This causes wrong variance comparisons and gives wrong Bullwhip Effect measures. To solve this problem and prevent wrong results, the Bullwhip Effect formula was improved in this study. Coefficient of variation formula adapted to defined Bullwhip Effect formula, and it's proven that this formula is more accurate and valid for all different Supply Chain studies.

As a result of simulation, the Bullwhip Effect measures are calculated for each different ordering policy. To make objective conclusion, each simulation result is analyzed by Minitab statistical software Packages.

The design of experiment is made by factorial design with two levels. The analysis results were valuable to make comments and suggestion for the improvements of Bullwhip Effect.

For standard out policy, it is proven that demand distribution, ordering cost, demand mean, demand variance, number of forecast periods, review period, lead time and safety factor have significant effect on Bullwhip Effect. And review period is the most important factor. To reduce the Bullwhip Effect, review period should be reduced too.

For lot for lot policy, demand distribution, ordering cost, demand mean, demand variance, number of forecast periods, review period, and lead time have significant effect on bullwhip. Review period is again the most important factor for this policy.

As seen here, factors can have similar effects in different ordering policies or diverse Supply Chain strategies. But there is also some common results as when review period is low bullwhip will also be low and same conclusion can be made for lead time too.

But in real life the situations are different. Companies sometimes doesn't have chance to change review period or lead time. For this reason this study is made for all different factor combination. This means, may be Supply Chain member doesn't have capability to change one factor, but it's proven and shown that there should be some alternative solution to reduce bullwhip. In addition to this, the provided simulation tool can be used, to test which Supply Chain strategy can be selected according to predetermined factor limitations. Beside that, the effect of selected factors on cost measure or net stock amplification can be other selection criteria for the solution of Supply Chain problem.

As a conclusion, this study managed to detect significant factors that effect Bullwhip and shows alternative solution strategies of Bullwhip Effect. Additionally new Supply Chain Simulation tool and improved Bullwhip Effect formula is illustrated to motivate better and improved studies in Supply Chain literature and solutions for real case problems.

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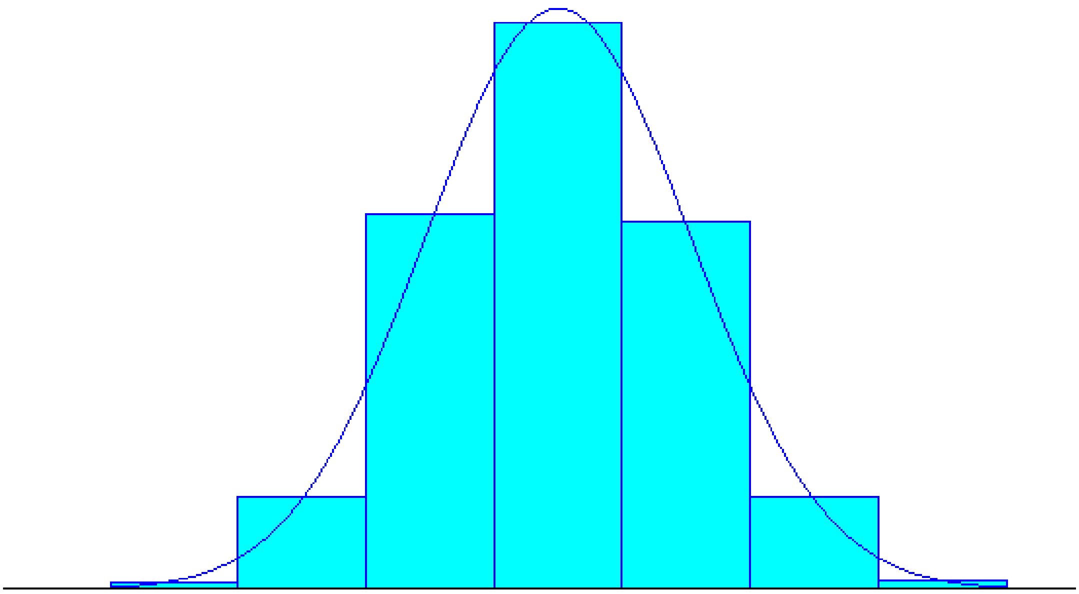
APPENDIX

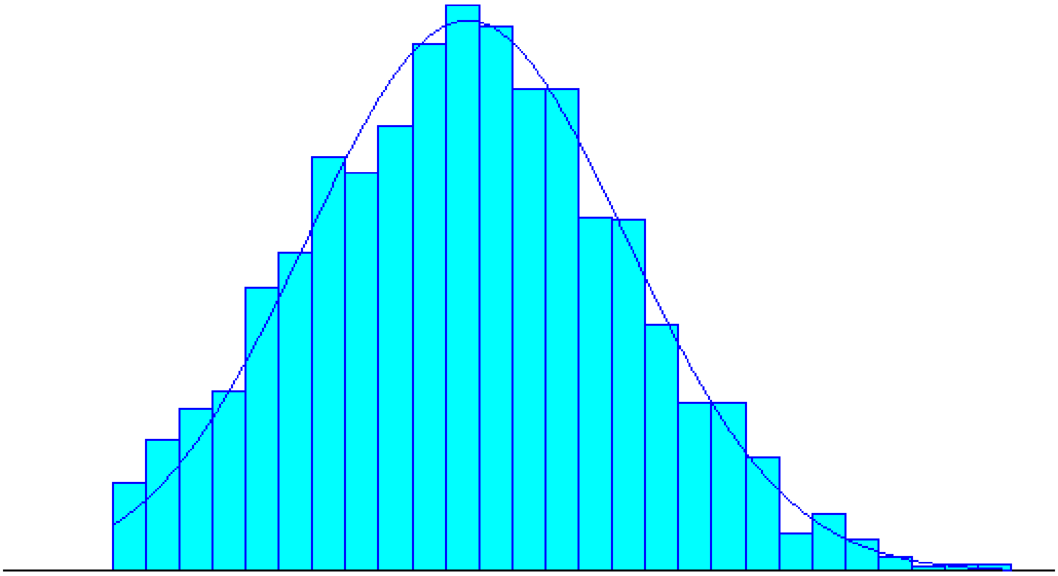


```
       Distribution Summary

Distribution:   Normal
Expression:     NORM(9.99, 1.04)
Square Error:   0.000136

Chi Square Test
  Number of intervals   = 7
  Degrees of freedom    = 4
  Test Statistic        = 10.7
  Corresponding p-value = 0.0319
```

Figure A.1: Input analyzer results of random demand generation for normal distribution with mean 10 and variance 1

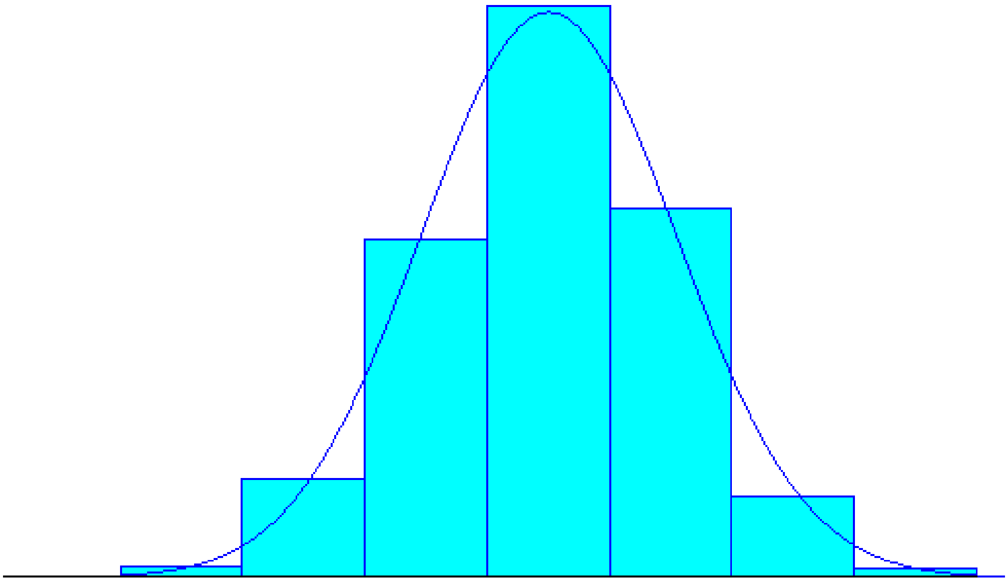


```
       Distribution Summary

Distribution:   Normal
Expression:     NORM(10.1, 4.77)
Square Error:   0.000428

Chi Square Test
  Number of intervals   = 24
  Degrees of freedom    = 21
  Test Statistic        = 42.5
  Corresponding p-value < 0.005
```

Figure A.2: Input analyzer results of random demand generation for normal distribution with mean 10 and variance 5



```
       Distribution Summary

Distribution:   Normal
Expression:     NORM(25, 1.04)
Square Error:   0.000711

Chi Square Test
  Number of intervals   = 7
  Degrees of freedom    = 4
  Test Statistic        = 18.9
  Corresponding p-value < 0.005
```

Figure A.3: Input analyzer results of random demand generation for normal distribution with mean 25 and variance 1

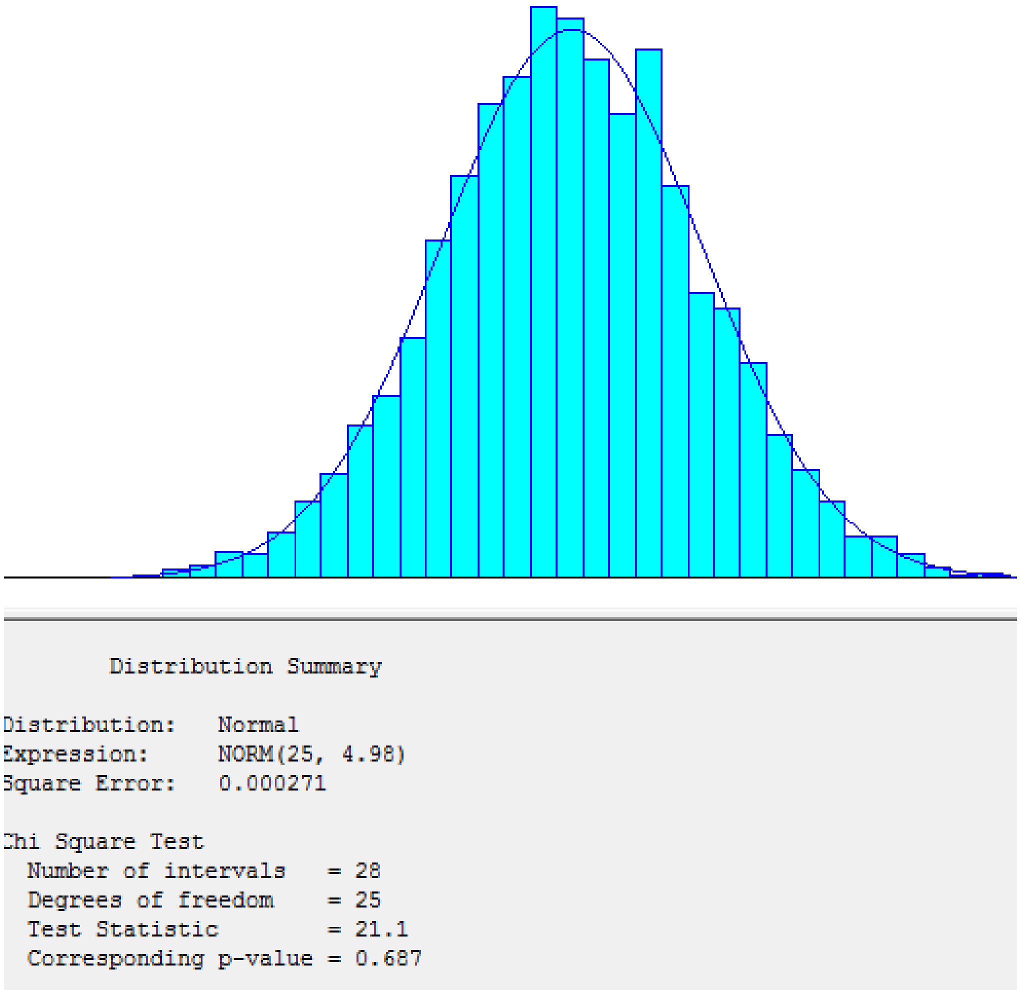
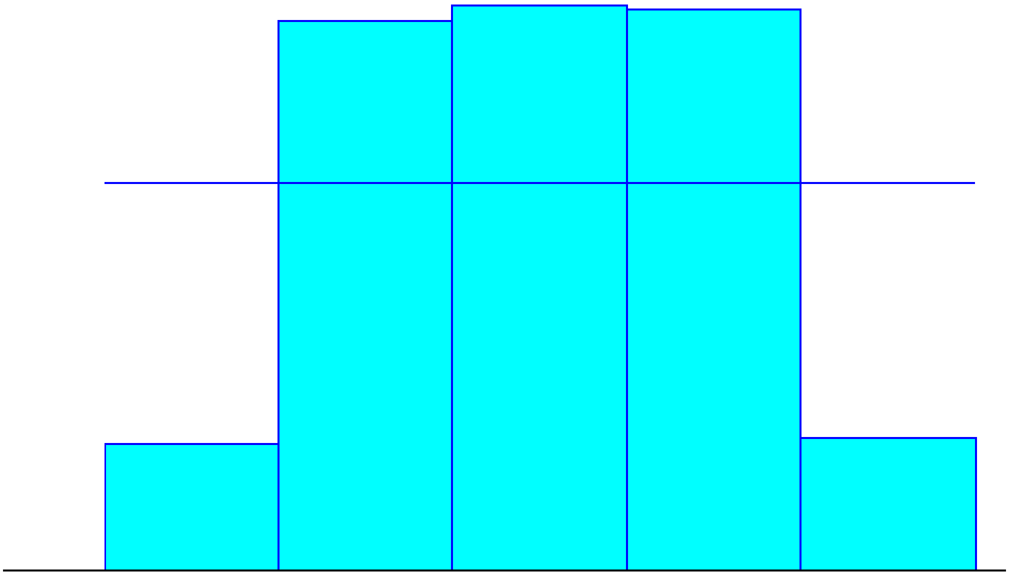


Figure A.4: Input analyzer results of random demand generation for normal distribution with mean 25 and variance 5



```
       Distribution Summary

Distribution:   Uniform
Expression:     UNIF(7.5, 12.5)
Square Error:   0.058471

Chi Square Test
  Number of intervals   = 5
  Degrees of freedom    = 4
  Test Statistic        = 1.2e+003
  Corresponding p-value < 0.005
```

Figure A.5: Input analyzer results of random demand generation for uniform distribution with a=8 and b=12 (mean 10 and variance 1)

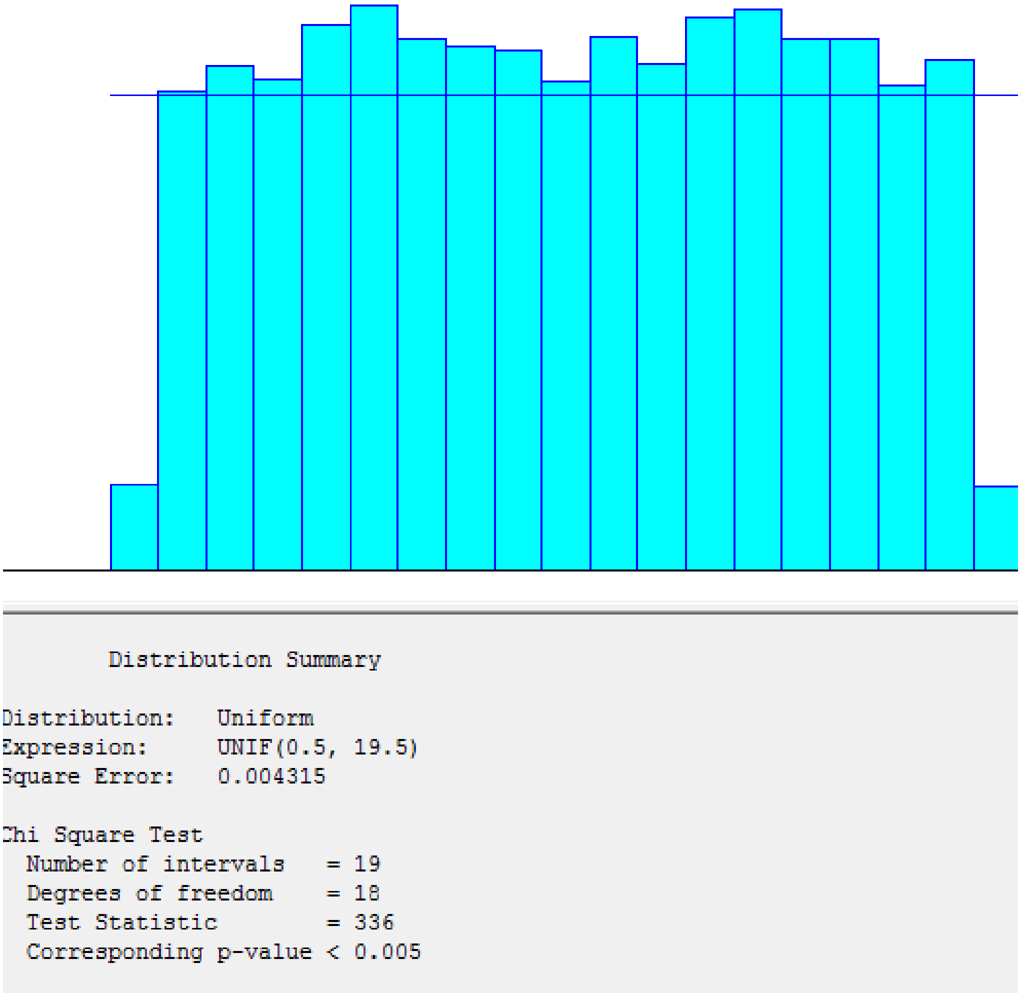


Figure A.6: Input analyzer results of random demand generation for uniform distribution with a=1 and b=19 (mean 10 and variance 5)

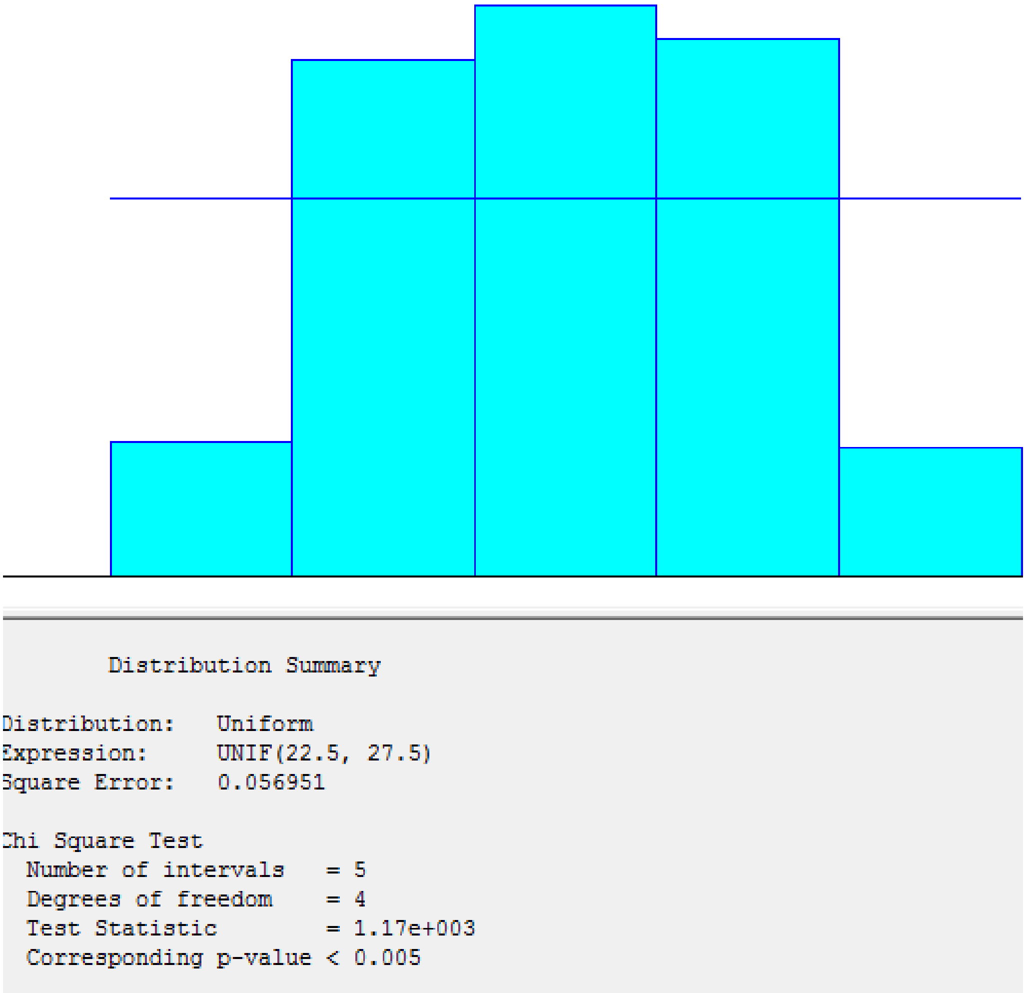
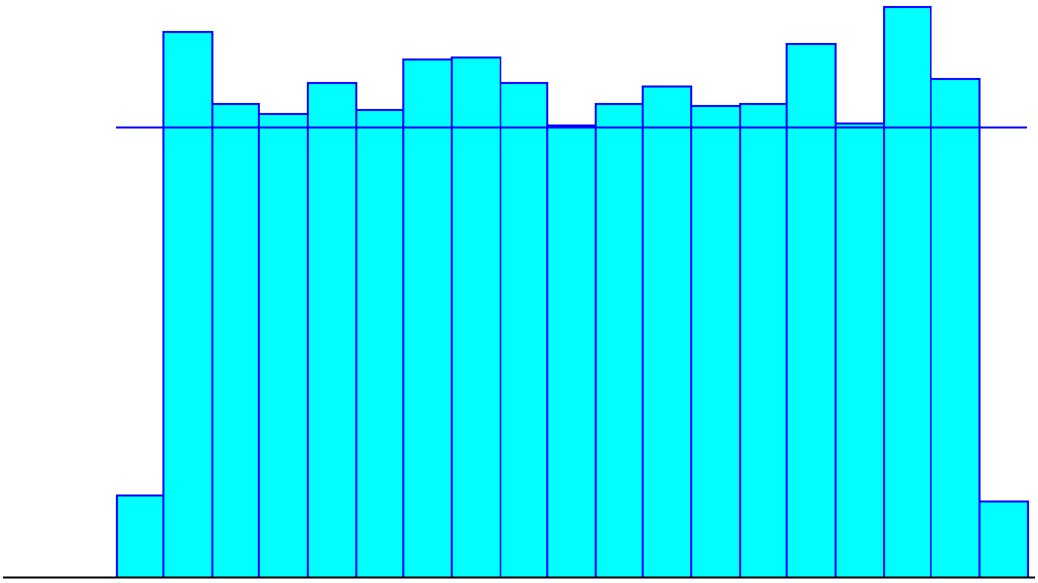


Figure A.7: Input analyzer results of random demand generation for uniform distribution with a=23 and b=27 (mean 25 and variance 1)



```
        Distribution Summary

Distribution:   Uniform
Expression:     UNIF(15.5, 34.5)
Square Error:   0.004423

Chi Square Test
  Number of intervals   = 19
  Degrees of freedom    = 18
  Test Statistic        = 345
  Corresponding p-value < 0.005
```

Figure A.8: Input analyzer results of random demand generation for uniform distribution with a=16 and b=34 (mean 25 and variance 5)

1. Define a demand pattern: uniform **2. Select test number:** 512

2. Define the demand parameters:

1	128	M-N
129	256	M-U
257	384	E-N
385	512	E-U

mean demand	$\bar{D}$	25,00
autoregressive coefficien	ρ	0
variance of error term	σ^2_ε	5,00
variance demand	σ^2_D	5,00

physical lead time	Tp	1
review period	Rp	1
total lead time	L	2
lead time demand	$\bar{D}_L$	50,00
stddev lead time demand	σ_L	3,16
safety factor	z	2,33

unit holding cost per period	Ch	1,00
unit backlog cost per period	Cb	1,00
unit ordering cost per period	Co	0,00
safety stock	SS	7,36

3. Define a demand forecasting technique:

EXPONENTIAL SMOOTHING

4. Define the demand forecasting parameters:

number of periods	Tm	15
smoothing parameter	α	0,125
signaling factor	χ	1,00

OUTPUTS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	AVG
TOTAL HOLDING COST 300*20	R	23	11	31	8	20	21	39	10	27	15	29	30	16	23	10	22	5	25	25	41	
TOTAL BACKLOG COST 300*20	T	3463	3514	3523	3478	3515	3523	3496	3503	3506	3496	3514	3487	3489	3455	3505	3501	3497	3537	3469	3519	
TOTAL ORDERING COST 300*20	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
TOTAL COST 300*20		3485	3525	3553	3486	3535	3544	3535	3514	3534	3511	3544	3517	3505	3478	3516	3523	3502	3562	3494	3560	
NET STOK AMPLIFICATION 300*20	U	2,37	2,26	2,42	2,23	2,33	2,44	2,48	2,12	2,41	2,25	2,42	2,26	2,17	2,25	2,38	2,47	2,02	2,31	2,27	2,47	2,32
BULLWHIP 300*20		1,27	1,27	1,29	1,25	1,26	1,25	1,30	1,25	1,29	1,25	1,29	1,27	1,25	1,27	1,25	1,27	1,26	1,28	1,28	1,31	1,27

5. Click the button to run the model

SIMULATE

6. See the results below:

period	receive	demand	NS	WIP	demand forecast	OUT-level	order LFL	holding costs	ordering costs	backorder costs
			20		25,00		25			
1	25	17	28	25	23,97	55	2	28,25	0,00	0,00
2	25	21	33	2	23,54	54	20	32,74	0,00	0,00
3	2	33	2	20	24,70	57	35	1,92	0,00	0,00
4	20	22	0	35	24,37	56	21	0,00	0,00	0,15
5	35	31	4	21	25,15	58	32	4,22	0,00	0,00
6	21	17	8	32	24,11	56	15	8,38	0,00	0,00
7	32	20	20	15	23,65	55	20	19,98	0,00	0,00
8	15	22	13	20	23,46	54	21	12,80	0,00	0,00
9	20	28	5	21	24,00	55	29	5,03	0,00	0,00
10	21	30	-4	29	24,78	57	32	0,00	0,00	4,23

Figure A.9: A Sample Simulation spreadsheet for standard out policy

ANOVA Results for Standard Out Policy						
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
demand forecast	1	0	0	0	0	1
demand distribution	1	255,61	255,61	255,61	577,63	0
Ordering cost	1	18,91	18,91	18,91	42,74	0
Holding cost	1	0	0	0	0	1
backorder cost	1	0	0	0	0	1
Mean	1	1094,65	1094,65	1094,65	2473,74	0
variance	1	767,14	767,14	767,14	1733,63	0
number of periods	1	101,96	101,96	101,96	230,41	0
review period	1	11541,4	11541,36	11541,4	26081,7	0
lead time	1	521,32	521,32	521,32	1178,11	0
service level	1	2,4	2,4	2,4	5,42	0,02
demand forecast*demand distribution	1	0	0	0	0	1
demand forecast*ordering cost	1	0	0	0	0	1
demand forecast*holding cost	1	0	0	0	0	1
demand forecast*backorder cost	1	0	0	0	0	1
demand forecast*mean	1	0	0	0	0	1
demand forecast*variance	1	0	0	0	0	1
demand forecast*number of periods	1	0	0	0	0	1
demand forecast*review period	1	0	0	0	0	1
demand forecast*lead time	1	0	0	0	0	1
demand forecast*service level	1	0	0	0	0	1
demand distribution*ordering cost	1	0,15	0,15	0,15	0,34	0,559
demand distribution*holding cost	1	0	0	0	0	1
demand distribution*backorder cost	1	0	0	0	0	1
demand distribution*mean	1	180,31	180,31	180,31	407,47	0
demand distribution*variance	1	564,82	564,82	564,82	1276,4	0
demand distribution *number of period	1	101,96	101,96	101,96	230,41	0
demand distribution *review period	1	60,39	60,39	60,39	136,47	0
demand distribution *lead time	1	27,01	27,01	27,01	61,04	0
demand distribution *service level	1	0,02	0,02	0,02	0,04	0,84
order cost*holding cost	1	0	0	0	0	1
order cost*backorder cost	1	0	0	0	0	1
order cost*mean	1	63,28	63,28	63,28	143,01	0
order cost*variance	1	840,09	840,09	840,09	1898,47	0
order cost*number of periods	1	101,96	101,96	101,96	230,41	0
order cost*review periods	1	13,99	13,99	13,99	31,62	0

Figure A.10: ANOVA results for Bullwhip with Standard out Policy

order cost*lead time	1	0,03	0,03	0,03	0,06	0,807
holding cost*backorder cost	1	0	0	0	0	1
holding cost*mean	1	0	0	0	0	1
holding cost*variance	1	0	0	0	0	1
holding cost*number of periods	1	0	0	0	0	1
holding cost*review period	1	0	0	0	0	1
holding cost*lead time	1	0	0	0	0	1
holding cost*service level	1	0	0	0	0	1
backorder cost*mean	1	0	0	0	0	1
backorder cost*variance	1	0	0	0	0	1
backorder cost*number of periods	1	0	0	0	0	1
backorder cost*review period	1	0	0	0	0	1
backorder cost*lead time	1	0	0	0	0	1
backorder cost*service level	1	0	0	0	0	1
mean*variance	1	581,75	581,75	581,75	1314,66	0
mean*number of period	1	0	0	0	0	1
mean*review period	1	1092,78	1092,78	1092,78	2469,52	0
mean*lead time	1	5,95	5,95	5,95	13,45	0
mean*service level	1	0,62	0,62	0,62	1,39	0,238
variance*number of period	1	38,19	38,19	38,19	86,31	0
variance*review period	1	143,65	143,65	143,65	324,63	0
variance*lead time	1	7,88	7,88	7,88	17,81	0
variance*service level	1	0,01	0,01	0,01	0,01	0,907
number of period*review period	1	35,11	35,11	35,11	79,35	0
number of period*lead time	1	0,41	0,41	0,41	0,92	0,339
number of period*service level	1	0	0	0	0,01	0,932
review period*lead time	1	78,75	78,75	78,75	177,97	0
review period*service level	1	25,99	25,99	25,99	58,74	0
lead time*service level	1	0,02	0,02	0,02	0,04	0,84

Figure A.10: ANOVA results for Bullwhip with Standard out Policy continued

Estimated Effects and Coefficients for BULLWHIP					
Term	Effect	Coef	SE Coef	T	P
Constant		2,8515	0,00735	387,98	0
demand forecast	0	0	0,00735	0	1
demand distribution	0,3533	0,1766	0,00735	24,03	0
order cost	-0,0961	-0,048	0,00735	-6,54	0
holding cost	0	0	0,00735	0	1
backorder cost	0	0	0,00735	0	1
Mean	0,7311	0,3655	0,00735	49,74	0
Variance	-0,612	-0,306	0,00735	-41,64	0
number of period	-0,2231	-0,1116	0,00735	-15,18	0
review period	2,3739	1,187	0,00735	161,5	0
lead time	0,5045	0,2523	0,00735	34,32	0
service level	0,0342	0,0171	0,00735	2,33	0,02
demand forecast*demand distribution	0	0	0,00735	0	1
demand forecast*order cost	0	0	0,00735	0	1
demand forecast*holding cost	0	0	0,00735	0	1
demand forecast*backorder cost	0	0	0,00735	0	1
demand forecast*mean	0	0	0,00735	0	1
demand forecast*variance	0	0	0,00735	0	1
demand forecast*number of period	0	0	0,00735	0	1
demand forecast*review period	0	0	0,00735	0	1
demand forecast*lead time	0	0	0,00735	0	1
demand forecast*service level	0	0	0,00735	0	1
demand distribution *order cost	0,0086	0,0043	0,00735	0,58	0,559
demand distribution *holding cost	0	0	0,00735	0	1
demand distribution *backorder cost	0	0	0,00735	0	1
demand distribution *mean	-0,2967	-0,1484	0,00735	-20,19	0
demand distribution *variance	0,5252	0,2626	0,00735	35,73	0
demand distribution *number of period	-0,2231	-0,1116	0,00735	-15,18	0
demand distribution *review period	0,1717	0,0859	0,00735	11,68	0
demand distribution *lead time	0,1148	0,0574	0,00735	7,81	0
demand distribution *service level	-0,003	-0,0015	0,00735	-0,2	0,84
order cost*holding cost	0	0	0,00735	0	1
order cost*backorder cost	0	0	0,00735	0	1
order cost*mean	0,1758	0,0879	0,00735	11,96	0
order cost*variance	-0,6405	-0,3202	0,00735	-43,57	0
order cost*number of period	0,2231	0,1116	0,00735	15,18	0
order cost*review period	-0,0827	-0,0413	0,00735	-5,62	0
order cost*lead time	0,0036	0,0018	0,00735	0,24	0,807
order cost*service level	-0,0061	-0,003	0,00735	-0,41	0,678
holding cost*backorder cost	0	0	0,00735	0	1
holding cost*mean	0	0	0,00735	0	1
holding cost*variance	0	0	0,00735	0	1
holding cost*number of period	0	0	0,00735	0	1
holding cost*review period	0	0	0,00735	0	1
holding cost*lead time	0	0	0,00735	0	1

Figure A.11: Estimated Effects and Coefficients for Bullwhip with Standard out Policy

holding cost*service level	0	0	0,00735	0	1
backorder cost*variance	0	0	0,00735	0	1
backorder cost*number of period	0	0	0,00735	0	1
backorder cost*review period	0	0	0,00735	0	1
backorder cost*lead time	0	0	0,00735	0	1
backorder cost*service level	0	0	0,00735	0	1
mean*variance	-0,533	-0,2665	0,00735	-36,26	0
mean*number of period	0	0	0,00735	0	1
mean*review period	0,7305	0,3652	0,00735	49,69	0
mean*lead time	-0,0539	-0,027	0,00735	-3,67	0
mean*service level	0,0173	0,0087	0,00735	1,18	0,238
variance*number of period	-0,1366	-0,0683	0,00735	-9,29	0
variance*review period	-0,2648	-0,1324	0,00735	-18,02	0
variance*lead time	0,062	0,031	0,00735	4,22	0
variance*service level	0,0017	0,0009	0,00735	0,12	0,907
number of period*review period	-0,1309	-0,0655	0,00735	-8,91	0
number of period*lead time	0,0141	0,007	0,00735	0,96	0,339
number of period*service level	0,0012	0,0006	0,00735	0,09	0,932
review period*lead time	0,1961	0,098	0,00735	13,34	0
review period*service level	0,1127	0,0563	0,00735	7,66	0
lead time*service level	-0,003	-0,0015	0,00735	-0,2	0,84

Figure A.11: Estimated Effects and Coefficients for Bullwhip with Standard Out Policy continued

Least Squares Means for BULLWHIP		
demand forecast	Mean	SE Mean
1	2,851	0,01039
2	2,851	0,01039
demand distribution		
1	2,675	0,01039
2	3,028	0,01039
order cost		
1	2,900	0,01039
2	2,803	0,01039
holding cost		
1	2,851	0,01039
2	2,851	0,01039
backorder cost		
1	2,851	0,01039
2	2,851	0,01039
Mean		
1	2,486	0,01039
2	3,217	0,01039
Variance		
1	3,157	0,01039
2	2,545	0,01039
number of period		
1	2,963	0,01039
2	2,740	0,01039
review period		
1	1,665	0,01039
2	4,038	0,01039
lead time		
1	2,599	0,01039
2	3,104	0,01039
service level		
1	2,834	0,01039
2	2,869	0,01039
demand forecast*demand distribution		
1 1	2,675	0,01470
1 2	3,028	0,01470
2 1	2,675	0,01470
2 2	3,028	0,01470

Figure A.12: Least Square Means for Bullwhip with Standard out Policy

demand forecast*order cost			
1	1	2,900	0,01470
1	2	2,803	0,01470
2	1	2,900	0,01470
2	2	2,803	0,01470
demand forecast*holding cost			
1	1	2,851	0,01470
1	2	2,851	0,01470
2	1	2,851	0,01470
2	2	2,851	0,01470
demand forecast*backorder cost			
1	1	2,851	0,01470
1	2	2,851	0,01470
2	1	2,851	0,01470
2	2	2,851	0,01470
demand forecast*mean			
1	1	2,486	0,01470
1	2	3,217	0,01470
2	1	2,486	0,01470
2	2	3,217	0,01470
demand forecast*variance			
1	1	3,157	0,01470
1	2	2,545	0,01470
2	1	3,158	0,01470
2	2	2,545	0,01470
demand forecast*number of period			
1	1	2,963	0,01470
1	2	2,740	0,01470
2	1	2,963	0,01470
2	2	2,740	0,01470
demand forecast*review per			
1	1	1,665	0,01470
1	2	4,038	0,01470
2	1	1,665	0,01470
2	2	4,038	0,01470
demand forecast*lead time			
1	1	2,599	0,01470
1	2	3,104	0,01470
2	1	2,599	0,01470

Figure A.12: Least Square Means for Bullwhip with Standard out Policy continued

2	2	3,104	0,01470
demand forecast*service level			
1	1	2,834	0,01470
1	2	2,869	0,01470
2	1	2,834	0,01470
2	2	2,869	0,01470
demand distribution *order cost			
1	1	2,727	0,01470
1	2	2,622	0,01470
2	1	3,072	0,01470
2	2	2,984	0,01470
demand distribution *holding cost			
1	1	2,675	0,01470
1	2	2,675	0,01470
2	1	3,028	0,01470
2	2	3,028	0,01470
demand distribution *backorder cost			
1	1	2,675	0,01470
1	2	2,675	0,01470
2	1	3,028	0,01470
2	2	3,028	0,01470
demand distribution *mean			
1	1	2,161	0,01470
1	2	3,189	0,01470
2	1	2,811	0,01470
2	2	3,245	0,01470
demand distribution *variance			
1	1	3,243	0,01470
1	2	2,106	0,01470
2	1	3,072	0,01470
2	2	2,985	0,01470
demand distribution *number of period			
1	1	2,675	0,01470
1	2	2,675	0,01470
2	1	3,251	0,01470
2	2	2,805	0,01470
demand distribution *review period			
1	1	1,574	0,01470
1	2	3,776	0,01470

Figure A.12: Least Square Means for Bullwhip with Standard out Policy continued

1	2	3,776	0,01470
2	1	1,755	0,01470
2	2	4,301	0,01470
demand distribution *lead time			
1	1	2,480	0,01470
1	2	2,870	0,01470
2	1	2,718	0,01470
2	2	3,338	0,01470
demand distribution *service level			
1	1	2,656	0,01470
1	2	2,693	0,01470
2	1	3,012	0,01470
2	2	3,044	0,01470
order cost*holding cost			
1	1	2,900	0,01470
1	2	2,900	0,01470
2	1	2,803	0,01470
2	2	2,803	0,01470
order cost*backorder cost			
1	1	2,900	0,01470
1	2	2,900	0,01470
2	1	2,803	0,01470
2	2	2,803	0,01470
order cost*mean			
1	1	2,622	0,01470
1	2	3,177	0,01470
2	1	2,350	0,01470
2	2	3,257	0,01470
order cost*variance			
1	1	2,885	0,01470
1	2	2,914	0,01470
2	1	3,430	0,01470
2	2	2,177	0,01470
order cost*number of period			
1	1	3,123	0,01470
1	2	2,676	0,01470
2	1	2,803	0,01470
2	2	2,803	0,01470
order cost*review period			
1	1	1,671	0,01470

Figure A.12: Least Square Means for Bullwhip with Standard out Policy continued

1	2	4,128	0,01470
2	1	1,658	0,01470
2	2	3,949	0,01470
order cost*lead time			
1	1	2,649	0,01470
1	2	3,150	0,01470
2	1	2,549	0,01470
2	2	3,057	0,01470
order cost*service level			
1	1	2,879	0,01470
1	2	2,920	0,01470
2	1	2,789	0,01470
2	2	2,817	0,01470
holding cost*backorder cost			
1	1	2,851	0,01470
1	2	2,851	0,01470
2	1	2,851	0,01470
2	2	2,851	0,01470
holding cost*mean			
1	1	2,486	0,01470
1	2	3,217	0,01470
2	1	2,486	0,01470
2	2	3,217	0,01470
holding cost*variance			
1	1	3,157	0,01470
1	2	2,545	0,01470
2	1	3,157	0,01470
2	2	2,545	0,01470
holding cost*number of periods			
1	1	2,963	0,01470
1	2	2,740	0,01470
2	1	2,963	0,01470
2	2	2,740	0,01470
holding cost*review periods			
1	1	1,665	0,01470
1	2	4,038	0,01470
2	1	1,665	0,01470
2	2	4,038	0,01470
holding cost*lead time			
1	1	2,599	0,01470

Figure A.12: Least Square Means for Bullwhip with Standard out Policy continued

1	2	3,104	0,01470
2	1	2,599	0,01470
2	2	3,104	0,01470
holding cost*service level			
1	1	2,834	0,01470
1	2	2,869	0,01470
2	1	2,834	0,01470
2	2	2,869	0,01470
backorder cost*mean			
1	1	2,486	0,01470
1	2	3,217	0,01470
2	1	2,486	0,01470
2	2	3,217	0,01470
backorder cost*variance			
1	1	3,157	0,01470
1	2	2,545	0,01470
2	1	3,157	0,01470
2	2	2,545	0,01470
backorder cost*number of period			
1	1	2,963	0,01470
1	2	2,740	0,01470
2	1	2,963	0,01470
2	2	2,740	0,01470
backorder cost*review period			
1	1	1,665	0,01470
1	2	4,038	0,01470
2	1	1,665	0,01470
2	2	4,038	0,01470
backorder cost*lead time			
1	1	2,599	0,01470
1	2	3,104	0,01470
2	1	2,599	0,01470
2	2	3,104	0,01470
backorder cost*service level			
1	1	2,834	0,01470
1	2	2,869	0,01470
2	1	2,834	0,01470
2	2	2,869	0,01470
mean*variance			

Figure A.12: Least Square Means for Bullwhip with Standard out Policy continued

1	1	2,525	0,01470
1	2	2,446	0,01470
2	1	3,790	0,01470
2	2	2,645	0,01470
mean*number of period			
1	1	2,597	0,01470
1	2	2,374	0,01470
2	1	3,329	0,01470
2	2	3,105	0,01470
mean*review period			
1	1	1,664	0,01470
1	2	3,308	0,01470
2	1	1,665	0,01470
2	2	4,769	0,01470
mean*lead time			
1	1	2,207	0,01470
1	2	2,765	0,01470
2	1	2,992	0,01470
2	2	3,442	0,01470
mean*service level			
1	1	2,477	0,01470
1	2	2,494	0,01470
2	1	3,191	0,01470
2	2	3,243	0,01470
variance*number of period			
1	1	3,201	0,01470
1	2	3,114	0,01470
2	1	2,725	0,01470
2	2	2,366	0,01470
variance*review period			
1	1	1,838	0,01470
1	2	4,477	0,01470
2	1	1,491	0,01470
2	2	3,600	0,01470
variance*lead time			
1	1	2,936	0,01470
1	2	3,379	0,01470
2	1	2,262	0,01470
2	2	2,829	0,01470

Figure A.12: Least Square Means for Bullwhip with Standard out Policy continued

variance*service level			
1	1	3,141	0,01470
1	2	3,174	0,01470
2	1	2,527	0,01470
2	2	2,563	0,01470
number of period*review period			
1	1	1,711	0,01470
1	2	4,215	0,01470
2	1	1,618	0,01470
2	2	3,861	0,01470
number of period*lead time			
1	1	2,718	0,01470
1	2	3,208	0,01470
2	1	2,481	0,01470
2	2	2,999	0,01470
number of period*service level			
1	1	2,947	0,01470
1	2	2,980	0,01470
2	1	2,722	0,01470
2	2	2,758	0,01470
review period*lead time			
1	1	1,510	0,01470
1	2	1,819	0,01470
2	1	3,688	0,01470
2	2	4,389	0,01470
review period*service level			
1	1	1,704	0,01470
1	2	1,625	0,01470
2	1	3,965	0,01470
2	2	4,112	0,01470
lead time*service level			
1	1	2,581	0,01470
1	2	2,618	0,01470
2	1	3,088	0,01470
2	2	3,119	0,01470

Figure A.12: Least Square Means for Bullwhip with Standard out Policy continued

1. Define a demand pattern: uniform   **2. Select test number:** 1024

2. Define the demand parameters:

1	256	M-N
257	512	M-U
513	768	E-N
769	1024	E-U

mean demand	$\overline{D}$	25,00
autoregressive coefficien	ρ	0
variance of error term	σ^2_ε	5,00
variance demand	σ^2_D	5,00

physical lead time	Tp	5
review period	Rp	5
total lead time	L	10
lead time demand	$\overline{D}_L$	250,00
stddev lead time demand	σ_L	7,07
safety factor	z	2,33

unit holding cost per period	Ch	1,00
unit backlog cost per period	Cb	1,00
unit ordering cost per period	Co	100,00
safety stock	SS	16,45

3. Define a demand forecasting technique:

EXPONENTIAL SMOOTHING

4. Define the demand forecasting parameters:

number of periods	Tm	7
smoothing parameter	α	0,250
signaling factor	χ	1,00

OUTPUTS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	AVG
TOTAL HOLDING COST 300*20	R	286	422	420	351	421	468	437	382	397	470	388	359	465	388	311	484	459	406	415	364	
TOTAL BACKLOG COST 300*20	T	19750	18669	19209	19339	19281	19120	18915	19130	19331	18567	19733	19472	18608	18899	20480	18973	18433	19228	18424	19562	
TOTAL ORDERING COST 300*20	S	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	
TOTAL COST 300*20		22036	21091	21629	21690	21703	21588	21352	21512	21729	21037	22121	21830	21073	21287	22791	21457	20893	21634	20840	21926	
NET STOK AMPLIFICATION 300*20	U	3,71	3,99	4,16	3,69	3,84	3,83	3,84	3,63	4,13	3,73	3,93	3,67	3,82	4,00	3,80	3,94	3,98	4,02	3,75	3,86	**3,87**
BULLWHIP 300*20		2,33	1,71	2,50	1,73	2,33	2,50	2,63	2,36	2,24	2,08	2,07	2,57	3,20	2,02	2,30	2,51	2,24	2,62	2,45	2,57	**2,35**

5. Click the button to run the model

SIMULATE

6. See the results below:

period	receive	demand	NS	WIP	demand forecast	OUT-level	order LFL	holding costs	ordering costs	backorder costs
			20		25,00		25			
1	25	17	28	125	22,94	0,00	239	28,25	100,00	0,00
2	25	21	33	339	22,33	0,00	0	32,74	0,00	0,00
3	25	33	25	314	24,95	0,00	0	24,92	0,00	0,00
4	25	22	28	289	24,23	0,00	0	27,85	0,00	0,00
5	25	31	22	264	25,83	0,00	0	22,22	0,00	0,00
6	25	17	30	239	23,58	0,00	0	30,38	0,00	0,00
7	25	20	35	214	22,79	0,00	0	34,98	0,00	0,00
8	25	22	38	189	22,63	0,00	0	37,80	0,00	0,00
9	25	28	35	164	23,92	0,00	0	35,03	0,00	0,00
10	25	30	30	139	25,50	0,00	0	29,77	0,00	0,00

Figure A.13: A Sample Simulation spreadsheet for lot for lot policy

ANOVA Results for Lot for Lot Policy						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
forecast technique	1	0	0	0	0	1
demand distribution	1	16,067	16,067	16,067	575,76	0
order cost	1	12,606	12,606	12,606	451,74	0
holding cost	1	0	0	0	0	1
backorder cost	1	0	0	0	0	1
demand mean	1	28,228	28,228	28,228	1011,53	0
demand variance	1	83,028	83,028	83,028	2975,21	0
number of forecast periods	1	4,519	4,519	4,519	161,93	0
review periods	1	3477,259	3477,259	3477,259	124604	0
lead time	1	1434,002	1434,002	1434,002	51386	0
service level	1	0	0	0	0	1
forecast technique*demand distribution	1	0	0	0	0	1
forecast technique*order cost	1	0	0	0	0	1
forecast technique*holding cost	1	0	0	0	0	1
forecast technique*backorder cost	1	0	0	0	0	1
forecast technique*demand mean	1	0	0	0	0	1
forecast technique*demand variance	1	0	0	0	0	1
forecast technique*	1	0	0	0	0	1
number of forecast periods						
forecast technique*review periods	1	0	0	0	0	1
forecast technique*lead time	1	0	0	0	0	1
forecast technique*service level	1	0	0	0	0	1
demand distribution *order cost	1	0,076	0,076	0,076	2,71	0,1
demand distribution *holding cost	1	0	0	0	0	1
demand distribution *backorder cost	1	0	0	0	0	1
demand distribution *demand mean	1	4,001	4,001	4,001	143,37	0
demand distribution *demand variance	1	22,386	22,386	22,386	802,19	0
demand distribution *	1	4,466	4,466	4,466	160,05	0
number of forecast periods						
demand distribution *review periods	1	7,639	7,639	7,639	273,74	0
demand distribution *lead time	1	1,021	1,021	1,021	36,57	0
demand distribution *service level	1	0	0	0	0	1
order cost*holding cost	1	0,002	0,002	0,002	0,06	0,8
order cost*backorder cost	1	0,002	0,002	0,002	0,06	0,8
order cost*demand mean	1	1,123	1,123	1,123	40,25	0

Figure A.14: ANOVA results for Bullwhip with Lot for Lot Policy

order cost*demand variance	1	77,144	77,144	77,144	2764,36	0
number of forecast periods						
holding cost*backorder cost	1	0	0	0	0	1
holding cost*demand mean	1	0	0	0	0	1
holding cost*demand variance	1	0	0	0	0	1
holding cost*	1	0	0	0	0	1
number of forecast periods						
holding cost*review periods	1	0	0	0	0	1
holding cost*lead time	1	0	0	0	0	1
holding cost*service level	1	0	0	0	0	1
backorder cost*demand mean	1	0	0	0	0	1
backorder cost*demand variance	1	0	0	0	0	1
backorder cost*	1	0	0	0	0	1
number of forecast periods						
backorder cost*review periods	1	0	0	0	0	1
backorder cost*lead time	1	0	0	0	0	1
backorder cost*service level	1	0	0	0	0	1
demand mean*demand variance	1	8,025	8,025	8,025	287,57	0
demand mean*	1	0	0	0	0	1
number of forecast periods						
demand mean*review periods	1	0,118	0,118	0,118	4,24	0
demand mean*lead time	1	0,16	0,16	0,16	5,74	0
demand mean*service level	1	0	0	0	0	1
demand variance*	1	0,393	0,393	0,393	14,07	0
number of forecast periods						
demand variance*review periods	1	2,346	2,346	2,346	84,08	0
demand variance*lead time	1	2,346	2,346	2,346	84,08	0
demand variance*service level	1	0	0	0	0	1
number of forecast periods*	1	0,001	0,001	0,001	0,04	0,8
review periods						
number of forecast periods*lead time	1	0,001	0,001	0,001	0,02	0,9
number of forecast periods*	1	0	0	0	0	1
service level						
review periods*lead time	1	232,552	232,552	232,552	8333,24	0
review periods*service level	1	0	0	0	0	1
lead time*service level	1	0	0	0	0	1

Figure A.14: ANOVA results for Bullwhip with Lot for Lot Policy continued

Estimated Effects and Coefficients for BULLWHIP					
Term	Effect	Coef	SE Coef	T	P
Constant		1,714	0,001846	928,66	0
forecast technique	0,0001	0	0,001846	0,03	0,979
demand distribution	-0,0886	-0,0443	0,001846	-23,99	0
order cost	-0,0785	-0,0392	0,001846	-21,25	0
holding cost	-0,0001	0	0,001846	-0,03	0,979
backorder cost	-0,0001	0	0,001846	-0,03	0,979
demand mean	0,1174	0,0587	0,001846	31,8	0
demand variance	-0,2013	-0,1007	0,001846	-54,55	0
number of forecast periods	-0,047	-0,0235	0,001846	-12,72	0
review periods	1,303	0,6515	0,001846	352,99	0
lead time	0,8368	0,4184	0,001846	226,68	0
service level	0,0001	0	0,001846	-0,03	0,979
forecast technique*demand distribution	0,0001	0	0,001846	0,03	0,979
forecast technique*order cost	0,0001	0	0,001846	0,03	0,979
forecast techn*holding cost	0,0001	0	0,001846	0,03	0,979
forecast technique*backorder cost	0,0001	0	0,001846	0,03	0,979
forecast technique*demand mean	0,0001	0	0,001846	0,03	0,979
forecast technique*demand variance	0,0001	0	0,001846	0,03	0,979
forecast technique*	0,0001	0	0,001846	0,03	0,979
number of forecast periods					
forecast technique*review periods	0,0001	0	0,001846	0,03	0,979
forecast technique*lead time	0,0001	0	0,001846	0,03	0,979
forecast technique*service level	0,0001	0	0,001846	0,03	0,979
demand distribution *order cost	-0,0061	-0,003	0,001846	-1,65	0,1
demand distribution *holding cost	0,0002	0,0001	0,001846	0,05	0,962
demand distribution *backorder cost	0,0002	0,0001	0,001846	0,05	0,962
demand distribution *demand mean	-0,0442	-0,0221	0,001846	-11,97	0
demand distribution *demand variance	0,1046	0,0523	0,001846	28,32	0
demand distribution *	-0,0467	-0,0233	0,001846	-12,65	0
number of forecast periods					
demand distribution *review periods	-0,0611	-0,0305	0,001846	-16,55	0
demand distribution *lead time	-0,0223	-0,0112	0,001846	-6,05	0
demand distribution *service level	0,0002	0,0001	0,001846	0,05	0,962
order cost*holding cost	0,0009	0,0005	0,001846	0,25	0,804
order cost*backorder cost	0,0009	0,0005	0,001846	0,25	0,804
order cost*demand mean	0,0234	0,0117	0,001846	6,34	0

Figure A.15: Estimated Effects and Coefficients for Bullwhip with Lot for Lot Policy

order cost*demand variance	0,1941	-0,097	0,001846	-52,58	0
number of forecast periods					
order cost*review periods	-0,0072	-0,0036	0,001846	-1,95	0,051
order cost*lead time	-0,0122	-0,0061	0,001846	-3,31	0,001
order cost*service level	0,0009	0,0005	0,001846	0,25	0,804
holding cost*backorder cost	-0,0001	0	0,001846	-0,03	0,979
holding cost*demand mean	-0,0001	0	0,001846	-0,03	0,979
holding cost*demand variance	-0,0001	0	0,001846	-0,03	0,979
holding cost*	-0,0001	0	0,001846	-0,03	0,979
number of forecast periods					
holding cost*review periods	-0,0001	0	0,001846	-0,03	0,979
holding cost*lead time	-0,0001	0	0,001846	-0,03	0,979
holding cost*service level	-0,0001	0	0,001846	-0,03	0,979
backorder cost*demand mean	-0,0001	0	0,001846	-0,03	0,979
backorder cost*demand variance	-0,0001	0	0,001846	-0,03	0,979
backorder cost*	-0,0001	0	0,001846	-0,03	0,979
number of forecast periods					
backorder cost*review periods	-0,0001	0	0,001846	-0,03	0,979
backorder cost*lead time	-0,0001	0	0,001846	-0,03	0,979
backorder cost*service level	-0,0001	0	0,001846	-0,03	0,979
demand mean*demand variance	-0,0626	-0,0313	0,001846	-16,96	0
demand mean*	-0,0001	0	0,001846	-0,03	0,979
number of forecast periods					
demand mean*review periods	-0,0076	-0,0038	0,001846	-2,06	0,04
demand mean*lead time	-0,0088	-0,0044	0,001846	-2,4	0,017
demand mean*service level	-0,0001	0	0,001846	-0,03	0,979
demand variance*	-0,0138	-0,0069	0,001846	-3,75	0
number of forecast periods					

Figure A.15: Estimated Effects and Coeff. For Bullwhip with Lot for Lot Policy cont.

demand variance*review periods	-0,0338	-0,0169	0,001846	-9,17	0
demand variance*service level	-0,0001	0	0,001846	-0,03	0,979
number of forecast periods*	-0,0007	-0,0004	0,001846	-0,2	0,845
review periods					
number of forecast periods*lead time	0,0005	0,0003	0,001846	0,14	0,886
number of forecast periods*	-0,0001	0	0,001846	-0,03	0,979
service level					
review periods*lead time	-0,337	-0,1685	0,001846	-91,29	0
review periods*service level	-0,0001	0	0,001846	-0,03	0,979
lead time*service level	-0,0001	0	0,001846	-0,03	0,979

Figure A.15: Estimated Effects and Coefficients for Bullwhip with Lot for Lot Policy continued

Least Squares Means for BULLWHIP			
forecast technique		Mean	SE Mean
1		1,7140	0,002610
2		1,7141	0,002610
demand distribution			
1		1,7583	0,002610
2		1,6697	0,002610
order cost			
1		1,7532	0,002610
2		1,6748	0,002610
holding cost			
1		1,7141	0,002610
2		1,7140	0,002610
backorder cost			
1		1,7141	0,002610
2		1,7140	0,002610
demand mean			
1		1,6553	0,002610
2		1,7727	0,002610
demand variance			
1		1,8147	0,002610
2		1,6133	0,002610
number of forecast period			
1		1,7375	0,002610
2		1,6905	0,002610
review period			
1		1,0625	0,002610
2		2,3655	0,002610
lead time			
1		1,2956	0,002610
2		2,1324	0,002610
service level			
1		1,7141	0,002610
2		1,7140	0,002610
forecast technique*demand distribution			
1	1	1,7583	0,003691
1	2	1,6696	0,003691
2	1	1,7583	0,003691

Figure A.16: Least Square Means for Bullwhip with Lot for Lot Policy

2	2	1,6698	0,003691
forecast technique*order cost			
1	1	1,7532	0,003691
1	2	1,6747	0,003691
2	1	1,7532	0,003691
2	2	1,6749	0,003691
forecast technique*holding cost			
1	1	1,7141	0,003691
1	2	1,7139	0,003691
2	1	1,7141	0,003691
2	2	1,7141	0,003691
forecast technique*backorder cost			
1	1	1,7141	0,003691
1	2	1,7139	0,003691
2	1	1,7141	0,003691
2	2	1,7141	0,003691
forecast technique*demand mean			
1	1	1,6553	0,003691
1	2	1,7726	0,003691
2	1	1,6553	0,003691
2	2	1,7728	0,003691
forecast technique*demand variance			
1	1	1,8147	0,003691
1	2	1,6132	0,003691
2	1	1,8147	0,003691
2	2	1,6134	0,003691
forecast technique*number of forecast period			
1	1	1,7375	0,003691
1	2	1,6904	0,003691
2	1	1,7375	0,003691
2	2	1,6906	0,003691
forecast technique*review period			
1	1	1,0625	0,003691
1	2	2,3654	0,003691
2	1	1,0625	0,003691
2	2	2,3656	0,003691
forecast technique*lead time			
1	1	1,2956	0,003691

Figure A.16: Least Square Means for Bullwhip with Lot for Lot Policy continued

1	2	2,1323	0,003691
2	1	1,2956	0,003691
2	2	2,1325	0,003691
forecast technique*service level			
1	1	1,7141	0,003691
1	2	1,7139	0,003691
2	1	1,7141	0,003691
2	2	1,7141	0,003691
demand distribution*order cost			
1	1	1,7945	0,003691
1	2	1,7221	0,003691
2	1	1,7120	0,003691
2	2	1,6275	0,003691
demand distribution*holding cost			
1	1	1,7584	0,003691
1	2	1,7582	0,003691
2	1	1,6697	0,003691
2	2	1,6698	0,003691
demand distribution*backorder cost			
1	1	1,7584	0,003691
1	2	1,7582	0,003691
2	1	1,6697	0,003691
2	2	1,6698	0,003691
demand distribution *demand mean			
1	1	1,6775	0,003691
1	2	1,8391	0,003691
2	1	1,6331	0,003691
2	2	1,7063	0,003691
demand distribution *demand variance			
1	1	1,9112	0,003691
1	2	1,6054	0,003691
2	1	1,7181	0,003691
2	2	1,6213	0,003691
demand distribution *number of forecast per			
1	1	1,7584	0,003691
1	2	1,7582	0,003691
2	1	1,7166	0,003691
2	2	1,6229	0,003691

Figure A.16: Least Square Means for Bullwhip with Lot for Lot Policy cont.

demand distribution*review period			
1	1	1,0762	0,003691
1	2	2,4404	0,003691
2	1	1,0487	0,003691
2	2	2,2907	0,003691
demand distribution*lead time			
1	1	1,3287	0,003691
1	2	2,1879	0,003691
2	1	1,2625	0,003691
2	2	2,0770	0,003691
demand distribution*service level			
1	1	1,7584	0,003691
1	2	1,7582	0,003691
2	1	1,6697	0,003691
2	2	1,6698	0,003691
order cost*holding cost			
1	1	1,7537	0,003691
1	2	1,7527	0,003691
2	1	1,6744	0,003691
2	2	1,6752	0,003691
order cost*backorder cost			
1	1	1,7537	0,003691
1	2	1,7527	0,003691
2	1	1,6744	0,003691
2	2	1,6752	0,003691
order cost*demand mean			
1	1	1,7062	0,003691
1	2	1,8002	0,003691
2	1	1,6044	0,003691
2	2	1,7452	0,003691
order cost*demand variance			
1	1	1,7569	0,003691
1	2	1,7496	0,003691
2	1	1,8725	0,003691
2	2	1,4771	0,003691
order cost*number of forecast per			
1	1	1,8006	0,003691
1	2	1,7059	0,003691

Figure A.16: Least Square Means for Bullwhip with Lot for Lot Policy cont.

2	1	1,6744	0,003691
2	2	1,6752	0,003691
1	2	2,4084	0,003691
2	1	1,0269	0,003691
2	2	2,3227	0,003691
order cost*lead time			
1	1	1,3287	0,003691
1	2	2,1777	0,003691
2	1	1,2625	0,003691
2	2	2,0871	0,003691
order cost*service level			
1	1	1,7537	0,003691
1	2	1,7527	0,003691
2	1	1,6744	0,003691
2	2	1,6752	0,003691
holding cost*backorder cost			
1	1	1,7141	0,003691
1	2	1,7141	0,003691
2	1	1,7141	0,003691
2	2	1,7139	0,003691
holding cost*demand mean			
1	1	1,6553	0,003691
1	2	1,7728	0,003691
2	1	1,6553	0,003691
2	2	1,7726	0,003691
holding cost*demand variance			
1	1	1,8147	0,003691
1	2	1,6134	0,003691
2	1	1,8147	0,003691
2	2	1,6132	0,003691
holding cost*number of forecast period			
1	1	1,7375	0,003691
1	2	1,6906	0,003691
2	1	1,7375	0,003691
2	2	1,6904	0,003691

Figure A.16: Least Square Means for Bullwhip with Lot for Lot Policy cont.

holding cost*review period			
1	1	1,0625	0,003691
2	2	2,3654	0,003691
holding cost*lead time			
1	1	1,2956	0,003691
1	2	2,1325	0,003691
2	1	1,2956	0,003691
2	2	2,1323	0,003691
holding cost*service level			
1	1	1,7141	0,003691
1	2	1,7141	0,003691
2	1	1,7141	0,003691
2	2	1,7139	0,003691
backorder cost*demand mean			
1	1	1,6553	0,003691
1	2	1,7728	0,003691
2	1	1,6553	0,003691
2	2	1,7726	0,003691
backorder cost*demand variance			
1	1	1,8147	0,003691
1	2	1,6134	0,003691
2	1	1,8147	0,003691
2	2	1,6132	0,003691
backorder cost*number of forecast period			
1	1	1,7375	0,003691
1	2	1,6906	0,003691
2	1	1,7375	0,003691
2	2	1,6904	0,003691
backorder cost*review period			
1	1	1,0625	0,003691
1	2	2,3656	0,003691
2	1	1,0625	0,003691
2	2	2,3654	0,003691
backorder cost*lead time			
1	1	1,2956	0,003691
1	2	2,1325	0,003691
2	1	1,2956	0,003691
2	2	2,1323	0,003691

Figure A.16: Least Square Means for Bullwhip with Lot for Lot Policy cont.

backorder cost*service level			
1	1	1,7141	0,003691
2	2	1,7139	0,003691
demand mean*demand variance			
1	1	1,7247	0,003691
1	2	1,5859	0,003691
2	1	1,9047	0,003691
2	2	1,6407	0,003691
demand mean*number of forecast period			
1	1	1,6787	0,003691
1	2	1,6319	0,003691
2	1	1,7962	0,003691
2	2	1,7492	0,003691
demand mean*review period			
1	1	1,0000	0,003691
1	2	2,3106	0,003691
2	1	1,1250	0,003691
2	2	2,4204	0,003691
demand mean*lead time			
1	1	1,2325	0,003691
1	2	2,0781	0,003691
2	1	1,3588	0,003691
2	2	2,1867	0,003691
demand mean*service level			
1	1	1,6553	0,003691
1	2	1,6553	0,003691
2	1	1,7728	0,003691
2	2	1,7726	0,003691
demand variance*number of forecast period			
1	1	1,8312	0,003691
1	2	1,7981	0,003691
2	1	1,6437	0,003691
2	2	1,5829	0,003691
demand variance*review period			
1	1	1,1462	0,003691
1	2	2,4831	0,003691
2	1	0,9787	0,003691

Figure A.16: Least Square Means for Bullwhip with Lot for Lot Policy cont.

2	2	2,2479	0,003691
demand variance*lead time			
2	1	1,2119	0,003691
2	2	2,0148	0,003691
demand variance*service level			
1	1	1,8147	0,003691
1	2	1,8147	0,003691
2	1	1,6134	0,003691
2	2	1,6132	0,003691
number of forecast period*review period			
1	1	1,0856	0,003691
1	2	2,3894	0,003691
2	1	1,0394	0,003691
2	2	2,3417	0,003691
number of forecast *service level			
1	1	1,7375	0,003691
1	2	1,7375	0,003691
2	1	1,6906	0,003691
2	2	1,6904	0,003691
review period*lead time			
1	1	0,4756	0,003691
1	2	1,6494	0,003691
2	1	2,1156	0,003691
2	2	2,6154	0,003691
review period*service level			
1	1	1,0625	0,003691
1	2	1,0625	0,003691
2	1	2,3656	0,003691
2	2	2,3654	0,003691
lead time*service level			
1	1	1,2956	0,003691
1	2	1,2956	0,003691
2	1	2,1325	0,003691
2	2	2,1323	0,003691

Figure A.16: Least Square Means for Bullwhip with Lot for Lot Policy continued

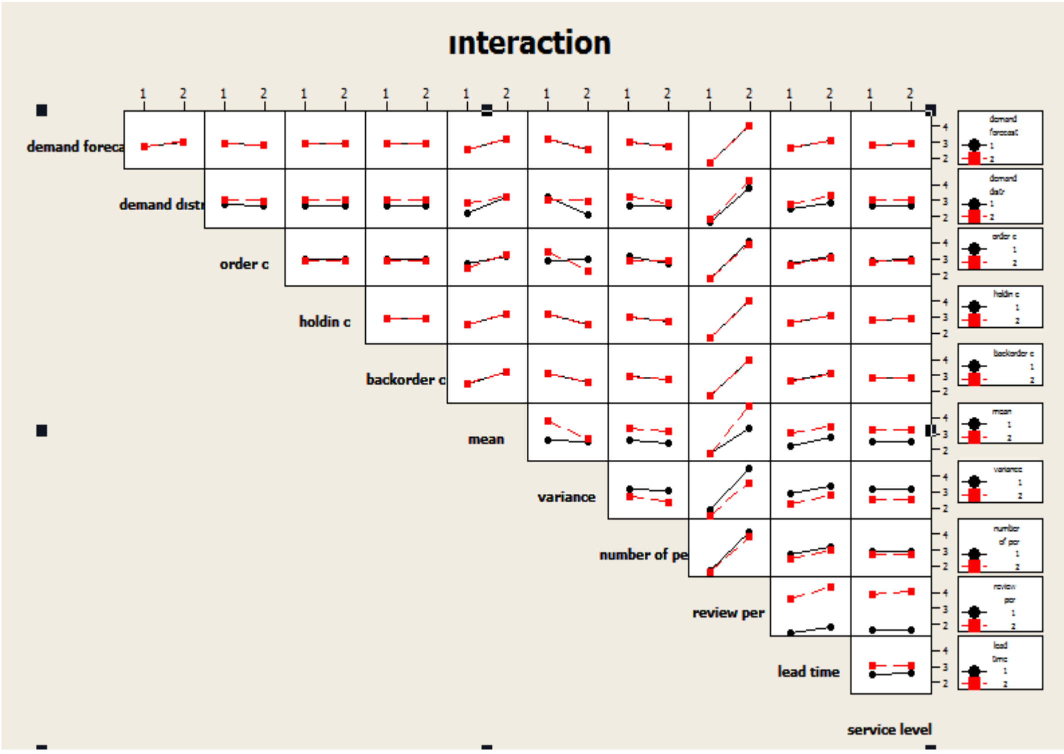


Figure A.17: Factors interaction plot for standard out policy

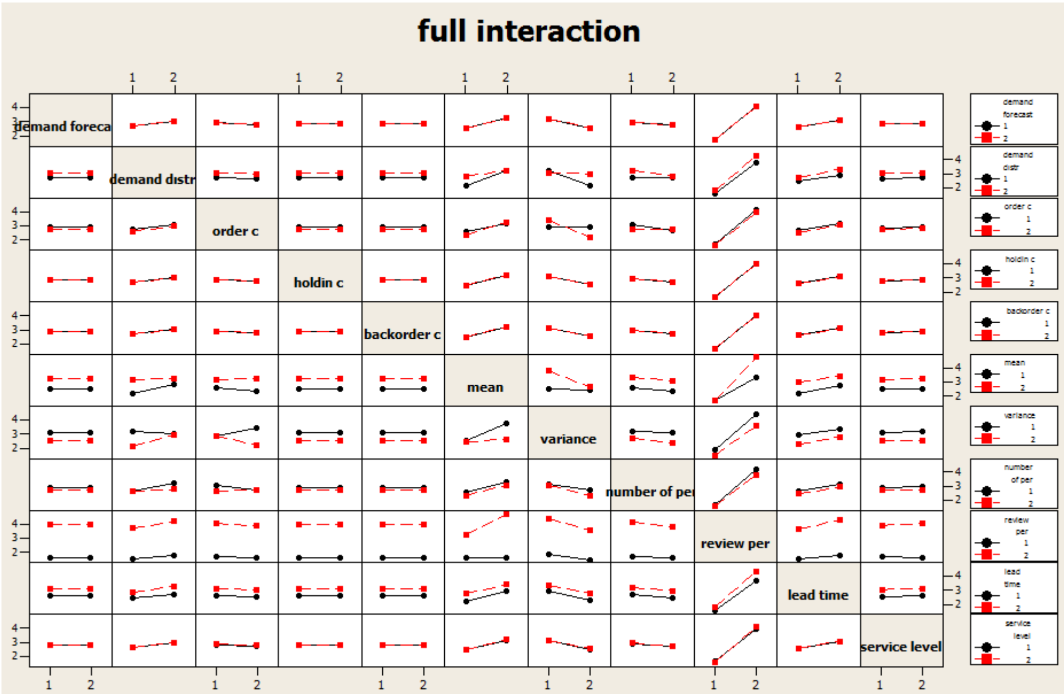


Figure A.18: Factors full interaction plot for standard out policy

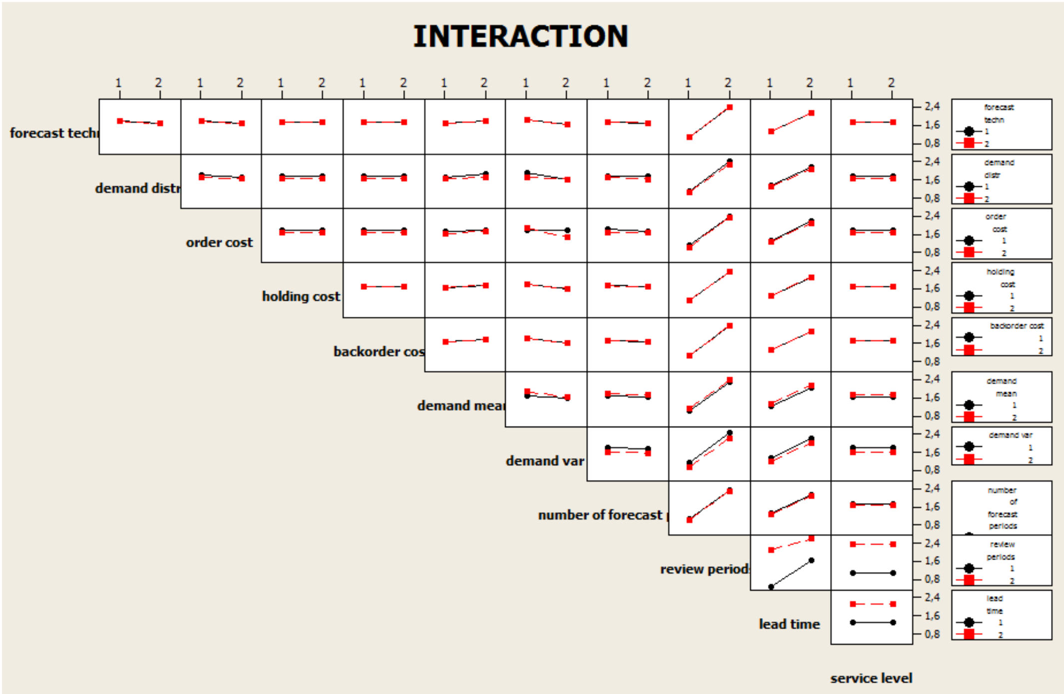


Figure A.19: Factors interaction plot for lot for lot policy

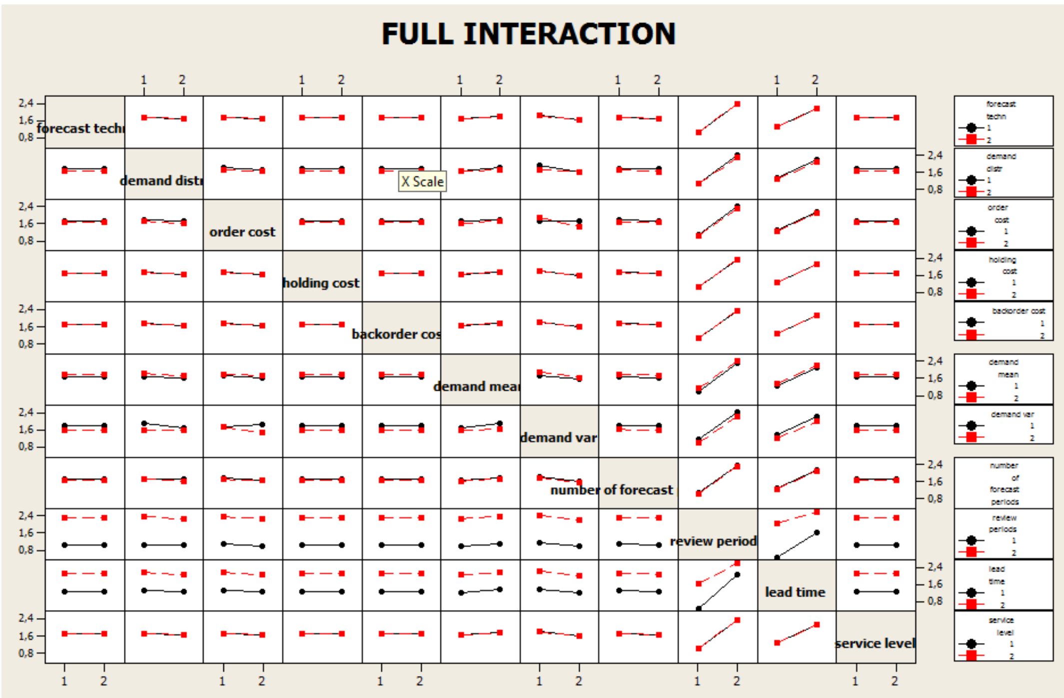


Figure A.20: Factors full interaction plot for lot for lot policy