A SIMULATION BASED DECISION SUPPORT SYSTEM FOR SUPPLY CHAIN MANAGEMENT

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by

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ABSTRACT

A SIMULATION BASED DECISION SUPPORT SYSTEM

FOR SUPPLY CHAIN MANAGEMENT

This study focuses on the improvement of supply chain performance in one of the biggest commodity product manufacturers in Turkey. The aim is to generate a tool that runs as a Decision Support System (DSS) and provides an easy to use simulation environment for supply chain managers in decision-making. In the current supply chain system there is no demand information flow upwards in the chain and the manufacturer determines its manufacturing rate according to the orders faced in the last thirty days. On the other hand, the manufacturer offers a volume discount option if the orders placed by a distributor exceed a certain quota. In the “Monthly Quota” system, the distributors gain a discount for their unit-purchasing price, if they reach their quota at the end of the evaluation period. As an improvement of the current supply chain system, an information system is proposed to share the Point of Sale data among the members of the supply chain. Another improvement strategy may be applying the “Rolling Horizon” instead of “Monthly Quota” method where the quotas are checked every time a distributor places an order. Three simulation models are developed by using the software ARENA, a graphical user interface that uses MS-Excel as a database is generated and integrated into a DSS for the supply chain managers. The DSS environment is used to compare all three models with different performance measures.

KISA ÖZET

TEDARİK ZİNCİRİ YÖNETİMİ İÇİN SİMULASYON TABANLI KARAR DESTEK SİSTEMİ

Bu çalışma, Türkiye'deki en büyük sarfiyat ürünü imalatçılarından birindeki tedarik zinciri performansını iyileştirmeye yöneliktir. Çalışmanın amacı, tedarik zinciri yöneticilerinin karar vermeleri için karar destek sistemi olarak çalışacak ve kullanımı kolay bir denetim ortamı sağlayacak bir çözüm geliştirmektir. Mevcut sistemde, zincirin yukarısına doğru bir talep bilgisi akışı bulunmamakta ve imalatçı firma imalat hızını kendisine son bir ayda verilen sipariş miktarlarına göre belirlemektedir. Diğer tarafta, dağıtıcıların verdiği toplam sipariş miktarının belirli bir kotanın üzerinde olması durumunda, dağıtıcılarına indirim uygulanmaktadır. "Aylık Kota" sisteminde, dağıtıcılar değerlendirme peryodu sonunda kotalarına ulaşmışlarsa, birim satınalma fiyatında indirim elde ederler. Mevcut tedarik zinciri sistem performansını iyileştirmek üzere satış noktası verilerinin tedarik zinciri üyeleri arasında paylaşımı için bir bilişim sistemi önerilmektedir. Bir başka iyileştirme stratejisi ise, "Aylık kota" yerine, kotaların dağıtımcı her sipariş verdiğinde kontrol edildiği "Yuvarlama Dönem" yöntemini uygulamak olabilir. ARENA yazılımı kullanılarak üç simulasyon modeli geliştirilmiş, MS-Excel'i veritabanı olarak kullanan bir grafik kullanıcı arayüzü oluşturulmuş, ve tedarik zinciri yöneticileri için bir karar destek sistemine entegre edilmiştir. KDS ortamı, değişik performans ölçütleriyle üç modelin karşılaştırmak için kullanılmıştır.

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It would be impossible to underestimate the never-ending patience and continuous moral support that my love Umut Yıldır has offered.

DEDICATION

To my sister and my parents, Duygu, Nurdan and Lütfü Sancar…

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ABBREVIATIONS

APS: Advanced Planning and Scheduling
CPFR: Collaborative Forecasting
DSS: Decision Support System
EDI: Electronic Data Interchange
ERP: Enterprise Resource Planning
GUI: Graphical User Interface
IS: Information System
IT: Information Technology
MIS: Management Information System
MS: Microsoft
MTS: Make to Stock
POS: Point of Sales
ROI: Return on Investment
SC: Supply Chain
SCM: Supply Chain Management
TPS: Transaction Processing System
VMI: Vendor Managed Inventory
VOI: Value of Information

CHAPTER 1

INTRODUCTION

A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. It is dynamic and requires a continuous flow of information, material and funds between different stages. The aim of a supply chain is to maximize the overall value generated, which is the difference between what the finished good is worth to the end customer and the effort the supply chain expends in filling the end customer's request.

In today's competitive market environment, managing the entire supply chain becomes a key factor for the successful business. With increased pressure from customers of the supply chain, commodity products manufacturers can no longer afford to operate supply chains. They should take actions to ensure their supply chains efficiently respond to rapidly changing customer demands. Industry competitors need to change the nature of their supply chain operations radically to become truly customer driven by effective and efficient use of Supply Chain Management (SCM). The expected benefits of SCM may be counted as improving throughput, reducing cycle times, reducing inventory costs, optimizing transportation, increasing order fill rates, predicting the disturbance to downstream and increasing customer responsiveness. Most of the firms began to realize the strategic importance of SCM to integrate and coordinate individual business functions across the supply chain and to make better decisions leading to efficiency and effectiveness.

In this master thesis, the supply chain for one of the biggest commodity product manufacturers in Turkey is analyzed through making interviews with the managers of the Strategic Planning Department. The pitfalls of the supply chain are determined and the opportunities to resolve the conflicting objectives of different supply chain units are developed. The state of the supply chain is modeled by utilizing a discrete event system simulation software, ARENA v.10.00.00. The models are integrated into a Decision Support System environment and enhanced by user interfaces.

The study focuses on the improvement of supply chain performance while maximizing the overall value generated. We consider a single manufacturing facility producing a commodity product and serving five distributors. In the current supply chain system, the manufacturer determines its manufacturing rate by forecasting, which is only based on the demand placed by the distributors in the last thirty days. There is no sharing of demand information in the supply chain, which leads to ineffective forecast results for the manufacturer. On the other hand, the manufacturer offers a volume discount option, when the orders placed by a distributor exceed a certain quota in a specific evaluation period. The quota is determined beforehand and may differ for each distributor according to the mutual agreement between them. The distributors gain a discount for their unit-purchasing price; if they reach their individual quota at the end of the evaluation period, which leads to an increase in the amount of orders at the end of the evaluation periods. This model of the supply chain leads to high inventory levels at the manufacturer during the period, high losses in sales at the distributors at the end of the periods and results in very low service levels for the supply chain and thus unsatisfied end-customers. This is actually a classical problem which is referred to as the "Hockey-Stick Phenomenon" in the literature (Chopra et al., 2004). An alternative solution for this problem is a rolling horizon policy, which we propose and discuss in detail in this study.

In this study we propose two new strategies for the current supply chain system where there is no information flow upwards in the supply chain. In the first strategy, we consider the current "Monthly Quota" system with full information sharing. In the second model we further improve the "Monthly Quota" system by allowing the monthly quota in a rolling horizon basis.

The current model and two proposed simulation models are integrated with an easy to use graphical user interface, to provide a Decision Support System (DSS) environment for the supply chain managers, who are able to change the input values of the supply chain and see how the supply chain reacts to these changes in terms of the generated performance measures in all three policies. The users of the system, namely the supply chain managers, may draw conclusions from the results, by using both summary tables and meaningful graphics provided by the decision support system.

The organization of the thesis is as follows: In Chapter 2, we give background information on supply chain management and coordination issues as well as the common performance measures used for supply chains. In Chapter 3, a review of related recent literature is provided for the assessment of the value of information sharing in supply chains and the use of simulation modeling in supply chain analysis. In Chapter 4, the current supply chain system and two proposed systems are described in detail. The analysis of the simulation models including the effect of information sharing and rolling horizon policy are discussed with numerical illustrations in Chapter 5. Chapter 6 includes the experimental design on the basic input parameters and the analysis of the results of the experiments with respect to selected performance measures. In Chapter 7, the generated decision support system framework is demonstrated with an illustrative example. Finally, in Chapter 8 the conclusions drawn from this study and possible future work are emphasized.

CHAPTER 2

BACKGROUND

Definition of Supply Chain Management

A supply chain is an inter-linked set of relationships connecting customer to supplier, perhaps through a number of intermediate stages such as manufacturing, warehousing and distribution (Agarwal et al., 2002). According to another definition, a supply chain may be defined as an integrated process wherein a number of business entities work together in an effort to acquire raw materials, convert these raw materials into specified final products and deliver these final products to retailers, who then satisfy the demand of the end customers of the supply chain (Beamon, 1998). It is characterized by a forward flow of materials and a backward flow of information, as seen in Figure 1.

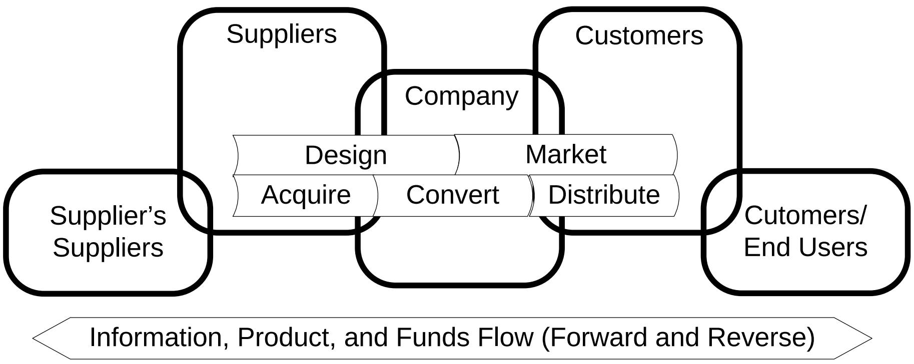


Figure 1. Overview of a supply chain

The primary purpose for the existence of a supply chain is to satisfy customer needs, in the process generating profits for itself (Chopra et al., 2004). In other words, the objective of the supply chain is to maximize the overall value generated, where the value is the difference between what the final products is worth to the customer and the effort the supply chain expends in satisfying the customer needs. To improve the value of the chain while maximizing revenue and minimizing costs as well as satisfying customers, the supply chains should be managed carefully. Supply Chain Management (SCM) is the process of integrating and utilizing the variety of stages like raw material/component suppliers, manufacturers, wholesalers/distributors, retailers and the customers so that goods are produced and delivered at the right time while minimizing costs as well as satisfying customer requirements (Stadtler, 2004).

There are five application areas of SCM: demand planning, master planning, procurement, transportation and manufacturing. Demand planning is used to reduce forecast errors by doing collaborative forecasting among all units of the supply chain. Master planning simultaneously aims to plan all of the material, capacity, transportation and other constraints across the supply chain. Procurement considers the vendor capacity, cost and lead time constraints to fulfill the raw material requirements, while transportation planning considers a way to find an optimal plan by identifying the dynamic transportation requirements. Finally the manufacturing deals with the constraints like material, capacity, etc., which also have impact on manufacturing.

Today’s rapidly growing, changing and thus competitive market environment requires an efficient and effective use of SCM to resolve the conflicting objectives of different supply chain units. The expected benefits of SCM may be counted as improving throughput, reducing cycle times, reducing inventory costs, optimizing transportation, increasing order fill rates, predicting the disturbance to downstream and increasing customer responsiveness (Heizer et al., 2006; Chang et al., 2001; Verstraete, 2005).

Supply Chain Coordination

Most of the firms began to realize the strategic importance of SCM to integrate and coordinate individual business functions across the supply chain. The coordination between each stage of the supply chain is critical, because the lack of coordination leads to less profit for the whole supply chain. This occurs if each stage of the supply chain only optimizes its local objective without considering the impact on the complete chain.

Supply chain managers should first identify the major obstacles leading to lack of coordination throughout the supply chain to take suitable actions that help achieve coordination. The actions may be aligning goals and incentives, improving information accuracy and operational performance, designing pricing strategies to stabilize orders and building partnerships and trust. A trust based relationship between two stages of a supply chain includes dependability. It involves the belief that each step is interested in the other's welfare and would not take actions without considering their impact on the other stage and this helps to improve the performance of the supply chain. A manager can help build trust and strategic partnerships by designing a relationship where the mutual benefit to both sides is clear, both parties are mutually independent, contracts are allowed to evolve over time, and conflicts are resolved effectively. Still, in addition to these, the achievement of the coordination in practice requires quantification of the bullwhip effect, getting the top management commitment, devoting resources for coordination, focus on communication with other stages, trying to achieve coordination in the entire supply chain network, the use of technology to improve connectivity and the sharing of the benefits of coordination equitably (Chopra et al., 2004).

The lack of coordination also results if there is information distortion within the supply chain. Procter and Gamble (P&G) called information distortion as "Bullwhip Effect" phenomenon, where the demand variability is amplified as moving up the supply chain, as seen in Figure 2. The possible symptoms of this phenomenon are counted as excessive inventory, poor product forecasts, insufficient or excessive capacities, poor customer service due to unavailable products, or long backlogs, uncertain production planning, and high costs for corrections, such as for expedited shipments and overtime (Lee et al., 1997b; Petrovic, 2001).

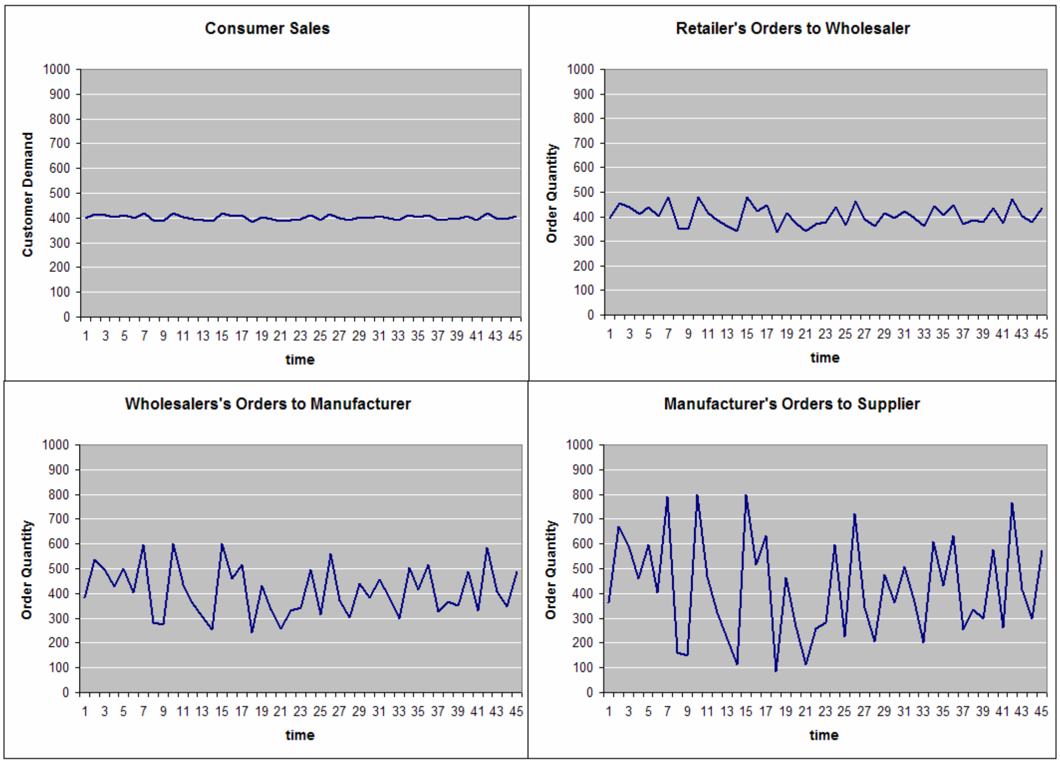


Figure 2. Illustration of the bullwhip effect

The Bullwhip Effect is created when upstream members of the supply chain collect the order data from an immediate downstream member and process it to produce their own forecasts. This repetitive processing of consumption data may be resolved by making the real demand data at the downstream site available to the upstream site, so that all members in the supply chain can update their forecasts using the same raw data. This may be possible by utilizing some sort of Information Technologies (IT) within the supply chain. The integration of information systems that enables the supply chain members to see the point-of-sale (POS) data of the downstream member may be counted as one remedy, whereas an electronic data interchange (EDI) system provides the real sharing and transmission of information among all members of the supply chain. The inventory and capacity information are also critical to make better decisions in the supply chain. Since EDI enables the sharing of this information in addition to the end customer demands, EDI is a relatively better solution compared to POS (Barlas et al., 2003). These technologies are utilized by some commercial software packages, called inter-enterprise computing, which enable open purchasing, collaborative forecasting and multi-enterprise shared computing (Uchneat, 1999; Stepherd, 1999). Open purchasing is used to tie the actual buyer and the vendor tightly together and keep the purchasing department somewhere in the loop, whereas the collaborative forecasting (CPFR) enables trading partners to share both demand and delivery forecasts, discuss them and agree on the results they will use.

It should be noted that although enabling the information flow in the supply chains seems easy, there are organizational, technological, financial and cultural barriers, whereas the most important one is trust (Childerhousei et al., 2003; Maynard, 2004).

With today's rapidly changing market conditions and customer needs, demand is extremely uncertain. There are many studies in the literature which prove that information sharing within the supply chain improves the performance of the supply chains by reducing the uncertainty of demand for the upstream members (Fiala, 2004; Mason-Jones et al., 2000; Li et al., 2005; Holweg et al., 2002).

Supply Chain Analysis and Performance Measures

The analysis and modeling of the supply chain is essential, since firms need to capture the synergy of inter-functional and inter-organizational integration and the coordination across the supply chain units to be able to make better decisions. The analysis is done to understand the key components of a supply chain. Without knowing which essential components of a supply chain must be managed, it is impossible to establish specific supply chain goals. On the other hand, the determination of such goals is a hard issue. Min et al. (2002) emphasize the absence of specific goals, due to the difficulty in developing appropriate performance measures.

The establishment of performance measures in supply chain analysis and modeling is very important in determining the efficiency and effectiveness. They may differ from one company to another, but there are some common ones. Beamon (1998) provides a detailed literature survey of performance measures for supply chains. In her study, the performance measures are categorized as qualitative and quantitative.

Qualitative performance measures are those which have no single direct numerical measurement. These include the flexibility, information and material flow integration, effective risk management, supplier performance and customer satisfaction, which is categorized further into three distinct groups: pre-transaction, transaction and post-transaction satisfaction.

Quantitative performance measures are grouped into two sub-categories: cost and customer responsiveness. The cost-based group consists of cost minimization, sales maximization, profit maximization, inventory investment minimization and return on investment (ROI) maximization. The second group, which is based on customer responsiveness, contains fill rate maximization, product lateness minimization, customer response time minimization, lead time minimization and function duplication minimization (Kleijnen et al., 2003; Beamon et al., 2001).

Beamon (1999) advocates the use of a mix of performance measures in addition to the common ones. The reason lies behind the fact that it is almost impossible to evaluate a Supply Chain Performance by using a single measure. There is usually more than one goal competing for higher supply chain performance. Thus any decision requires a trade-off analysis between the goals.

CHAPTER 3

LITERATURE SURVEY

This study aims at improving the performance of a supply chain by the use of information sharing and generating control policies by using simulation modeling. In this section, the latest research in the assessment of the value of information and the use of simulation for supply chain improvement are reviewed.

Assessment of the Value of Information Sharing in Supply Chains

In order to find the value of information in supply chains, one must first consider how it is measured. The Value of Information (VOI) is calculated, where VOI is defined as the trivial enhancement that a system attains through the use of additional information with respect to a base scenario. Basically, two types of scenarios are assessed during VOI studies: (i) Base Scenario, for a given set of information, and (ii) Information Studies, which are identical to the base scenario except some additional information is shared. Value of information is the marginal improvement that a system observes through the use of additional information relative to the base scenario.

Addressing VOI in the context of inventory management and comparing two or more scenarios and providing a numerical study to explore VOI over a set of varying operating characteristics are reviewed. According to Lee et al. (1997a, b), sources of uncertainty include the causes of the Bullwhip Effect: order batching, forecast updating, pricing, rationing and shortage gaming, from a demand-side perspective. On the supply side, uncertainty arises with regard to lead times, capacity availability, and product quality or yield. When firms do not replenish their inventory levels periodically and accumulate demands over time, the demand information for upstream members of the supply chain are distorted, which amplifies the order variability, and is followed by the prevention of matching the demand and supply of the supply chain.

Moinzadeh (2002) states that although it seems reasonable that the value of information should be substantial in such situations, order batching may not be a serious problem and the value of information is negligible. The base scenario in his study is a distribution supply chain with one supplier and N retailers that satisfy stochastic stationary demand. The supplier is restricted by the batch size Q, where the retailers follow an (r,Q) policy. In the scenario with information sharing, the supplier is able to see the retailers' inventory levels and uses them to better predict retailer orders. In both the base and information scenarios, the supplier knows the end-demand distribution and the replenishment policies of the retailers and the supply chain has a centralized decision-making mechanism to minimize the overall costs. In his study, the value of information is in a range between 0% and 23%.

The results show that the value of information is inversely proportional to the number of retailers, which is a situation that arises due to the system benefits from risk pooling with a large number of retailers. Moinzadeh (2002) also proves that the value of information is highly sensitive to lead times. It decreases as the ratio of the retailer's lead time to the overall system lead-time increases. The greater part of the safety stock is held at the supplier, assuming that the unit holding cost is lower at the supplier, and the retailer's lead time is small. Consequently, the reduction in supplier's safety stock that arises from information-sharing will have a larger impact.

Cheung and Lee (2000) also study one supplier, N Retailer supply chain, but their focus is on the reduction of the transportation costs by the replenishment coordination between retailers. They show that coordination alone dominates the base model, whereas it is not universally true.

Cachon (1999) addresses the value of scheduled order policies in one supplier, N retailer supply chain. The retailers are restricted to placing orders once every T periods. Forcing the retailers to order within a specific time sequence results in lower supply chain costs, whereas there are further complications. Cachon concludes that it is not reasonable to increase the order intervals, holding all else constant, to lower the supplier's demand variance since this generally increases costs for retailers.

Gavirmeni et al. (1999) explore the effect of a supplier's capacity restriction. The authors measure the value of information only with respect to the change in cost performance of the supplier. In the base scenario, the supplier has only the order history of its retailer. In their study, two scenarios with information sharing are evaluated. In the first scenario, the retailer shares information about the demand and the parameters of its order policy. In the second scenario, the retailer shares its inventory levels additionally. In the first case, the value of information varies in a range of 10% to 90%. But it increases with the availability of capacity. The marginal improvement from the first to second scenario is also variable, which is between 1% and 35%. A similar study by Simchi-Levi and Zhao (2003a, b) achieve similar results to Gavirmeni et al. (1999), evaluating the benefits of information sharing for a capacitated supplier. Both studies show that by sharing the demand information, the supplier gains inventory holding costs reduction by 5% to 35%.

Similar to order-batching studies, there are also studies evaluating the value of information through forecast updating yielding similar results. In such studies, the base scenarios are regarding to multi-echelon supply chains, members at each echelon make their own forecasts based on their own demand information. Related to this business problem, some different information sharing strategies to improve the performance of the supply chain are addressed in the literature, which are collaborative forecasting or shared forecasts, so that all members of the supply chain use a single forecast data (Aviv, 2001, 2002); sharing final demand information or other market signals with upstream members, so that better forecasts are possible for the upstream members (Lee et al. 1996, 2000; Ragunathan, 2001; Chen et al. 2005; Zhao and Xie, 2002); and sharing inventory information with upstream members, to enable a Vendor Managed Inventory (VMI) relationship (Aviv, 2002).

Shared information is used by the supplier to better predict the demand in the context of timing and quantity. When the supply chain has a centralized decision-making mechanism, it is also possible to coordinate the replenishment policies with an objective of maximizing the overall performance of the supply chain (Aviv, 2001, 2002; Chen, et al., 2005), rather than the individual performance of the members in a decentralized setting (Lee, et al., 2000; Raghunathan, 2001; Zhao and Xie, 2002).

Lee et al. (2000) explores the value of information in a supply chain that contains one supplier and one retailer. According to the assumptions of the model, the value of information is the supplier's ability to reduce its demand uncertainty through information sharing with its retailer. In the base scenario, the supplier determines the size and timing of its replenishment according to the final demand process and the last retailer order. In the information scenario, the retailer shares its realized demands in each period. The results show that the value of information is increasing with respect to the lead time of the manufacturer and is quite substantial. Raghunathan (2001) further expands the study of Lee et al. (2000) by adding the statement that the supplier can improve its prediction of retail orders substantially when using the full history of orders, rather than restricting its prediction to its last observed order.

Van der Duyn Schouten et al. (1994) explores the sharing of capacity information with a retailer. It is found that the inventory holding costs are reduced relative to the case when the supplier does not share capacity information. The value of information is expressed as the reduction of the holding costs due to the improved inventory control and it ranges from 8% to 31%. Similarly, Chen and Yu (2005) evaluate the value of lead-time information shared between the members of a supply chain. This study shows that the value of information decreases with respect to higher demand variability, higher penalty costs and lower lead-time variability and is small for low-volume items, whereas it can be significant for high-volume items.

In the literature review, several sources of uncertainty and types of information sharing strategies are addressed as potential determinants of value of information in supply chains. However, it remains unclear which determinants are most influential.

Use of Simulation in Supply Chain Analysis and Modeling

As discussed by several studies in the literature and confirmed by Jain et al. (2001; Mielke, 1999), simulation modeling is a suitable tool for analyzing supply chains. Its capability of capturing uncertainty and complexity makes it attractive for the purpose. Simulation modeling provides a virtual environment that looks, feels and behaves like a real workspace, which enables users to understand the overall supply chain processes and characteristics by graphics and animation techniques provided by simulation tools, while capturing the dynamics of the system by means of utilizing the probability distributions and the use of unexpected events. The simulation model also gives the users freedom to make mistakes and learn the reactions of the system to certain actions by playing with the simulation model without interrupting the real system. It enables powerful "what-if" analyses to test several strategies and scenarios; on the other hand, it permits the comparison of various operational alternatives leading to better future decision (Chang et al., 2001; Kleijnen, 2003; Montazer et al., 2003; Banks et al., 2002).

Another benefit of using simulation in supply chain modeling is the provided time compression to make timely decisions. Some well-designed simulation models enable users to monitor the system status and performance and make decisions in real time. However, some technology requirements should be met to run such a complex model within a very short time. First of all, it should interface with the desired databases to obtain information and to assign tasks and receive feedback on system status and performance. Although Enterprise Resource Planning (ERP) and Advanced Planning and Scheduling (APS) are used in most of the well-known firms, they are not capable of giving real time decisions, since they are concerned mainly with transaction processing. So, those systems may include simulation models as add-ons to provide the firm the ability to make real time decisions. As also mentioned by Terzi et al. (2004), among the quantitative methods which are utilized by ERP and APS, simulation is undoubtedly one of the most powerful techniques to apply as a Decision Support System (DSS) within a supply chain environment.

Many practitioners and academics seek optimality in supply chains, which will minimize the total cost while maximizing customer satisfaction. For this purpose optimization models and simulation models compete. Ingalls (1998) emphasizes that by the nature of optimization the optimal answer may change dramatically if there is a slight change in the inputs. A manager must know that a plan is robust, meaning that the variance in the business will not affect the overall answer drastically. Ingalls (1998) mentions that optimization misses some key business issues, like "demand variance" or "forecast error" which are the primary cause of the Bullwhip Effect Phenomenon (Ingalls et al., 1998). Simulation is always a better choice where business operations are too complicated to optimize and when variability is the key driver in the supply chain. In such a supply chain, an optimal answer may not be the best answer when considering the risk factor.

Supply chains may be modeled using dynamic simulation or discrete event simulation. Towill (1991) and Towill et al. (1991) use dynamic simulation to appraise the effects of various supply chain strategies to improve supply chain dynamics. However, most of the researchers and academics including Towill et al. (1991; Persson et al., 2002), claim that supply chains are typical environments for discrete event simulation.

When modeling the supply chain using simulation, one of the major issues is the level of detail at which each of the links in the chain should be modeled. The level of detail in any simulation model depends on the purpose of the effort. It should be defined carefully based on the objectives. Jain et al. (2001) define the selection of the included processes and their level of detail as the abstraction process. The goal of this process is to capture the essence of the behavior of the real system.

CHAPTER 4

THE SUPPLY CHAIN SYSTEM

The supply chain model considered in this study consists of a manufacturer, five distributors and many retailers, which build a complete supply chain as illustrated in Figure 3.

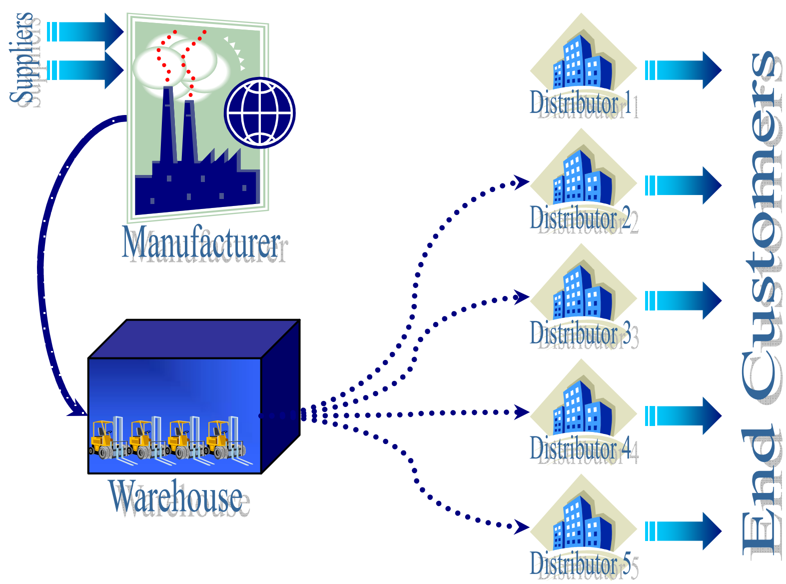


Figure 3. The supply chain model

The number of suppliers is assumed to be enough to satisfy all of the needed raw materials simultaneously, thus the manufacturer does not face any problems in the replenishment of raw materials. The manufacturer buys raw materials from its suppliers, converts these raw materials into finished goods and sells them to its distributors. The finished good of the supply chain is a commodity product.

Current System: Monthly Quota Strategy without Information Sharing

The manufacturer faces a great cost when there is a need to stop the continuous manufacturing system and start it again. Due to the nature of this continuous manufacturing system, the manufacturer prefers to work with a strategy of make-to-stock (MTS), and keeps its inventory in the warehouse, which is physically placed next to the factory. The physical capacity of the warehouse is a problematic constraint for the manufacturer, which produces for the inventory; because the manufacturer has to stop manufacturing when there is a capacity hit, which leads to a great cost, as mentioned before. The manufacturer may start its assembly line again, when the inventory level in the warehouse is less than or equal to 75% of the warehouse capacity. The manufacturer sets this rule, since it is working with MTS strategy; otherwise the frequency of its capacity hits may increase dramatically.

The manufacturer needs to forecast the demand of their distributors to determine its manufacturing rate. Since there is no demand information sharing among the supply chain, the manufacturer can only record the daily orders placed by their distributors and uses the thirty days moving averages of sales data to determine the amount to manufacture in the next day.

The only entity that feeds cash to the supply chain is the end customer, so the members of the supply chain, i.e., the manufacturer and its five distributors agree on a monthly order quota system to have a discount in the unit price. The quota agreement sets the minimum amount of total orders that should be given by a distributor in one month, which and may be different for each distributor. If the distributors reach their individual quota at the end of the month, they gain a discount for their unit-purchasing price.

The distributors manage their inventory with an (r-Q) policy and try to keep their inventory levels as low as possible. The reorder level (r) and the constant order quantity (Q) may be different for each distributor. The distributors monitor their inventory levels daily and decide to give orders of size Q, if the inventory level is equal to or less than the reorder level. On the other hand, at the end of every month, they check the total orders given to manufacturer in the current month and give extra orders so as to fulfill their monthly quota and gain the unit price discount in the next month.

Problems arise at the end of the month, when all distributors give their extra "End-of-Month" orders and the manufacturer's on-hand inventory is not enough to satisfy all of them. The manufacturer satisfies the demand of its distributors only with its on-hand inventory. It does not apply to order splitting, thus an order of a distributor has to be delayed until the order quantity may be fully satisfied with the finished goods in the inventory. However, the distributors can tolerate only a five-day delay of the manufacturer. Since the end product of the supply chain is a commodity, the service level is more important than the brand name, so it is more important to decrease the out-of-stock levels for the distributor (Hawker et al., 2004). Thus, after five days, if the manufacturer is still unable to fulfill the orders, the distributors cancel their orders, give up the discount they will get in the next month and buy another brand to satisfy their customers in order to decrease their out-of-stock levels on the shelf.

On the distributors' side, all unsatisfied orders are backordered. However, order splitting is possible for the distributors, thus the distributors may deplete their entire inventory to satisfy some of the orders immediately and backorder the unsatisfied portion.

Although the mutual agreement between the manufacturer and its distributors guarantees a minimum amount of orders to the manufacturer in a month, and introduces discounts for the distributors, it causes problems for both members of the supply chain in the long-run. During the first two-three weeks of a month the manufacturer keeps high inventory levels so that it can fulfill the increasing demand at the end of the month. This occasionally results in capacity hits, too. In spite of the high inventory levels during the month, the manufacturer may get into stockout position at the end of the month, if the "End-of-Month" demand of the distributors is relatively high. On the other side, the distributors face backorder or lost sales at the end of the month. This results in low fill rates and increased purchase costs for the distributors.

Monthly Quota Strategy with Information Sharing

As an improvement strategy, information sharing among the supply chain is recommended to minimize the errors of forecasting on the manufacturer's side and high costs arising due to these errors. If an information system exists between the members of the supply chain, the manufacturer can see the Point of Sale (POS) data of its distributors and make better forecasts.

Although the information sharing enables the manufacturer to make more accurate forecasts to determine the manufacturing rate, the manufacturer's inventory level is still affected by the distributor's extra "End-of-Month" orders in the long run. At the end of every month, when all five distributors place the extra order to fulfill their quota, the on-hand inventory may not be enough to satisfy all of them. Thus again, the distributors suffer delays in order fulfillment and this results in inefficiency for the whole supply chain with high costs, low service levels and unsatisfied end customers. To overcome this problem, the "Rolling Horizon" policy, instead of "Monthly Quota" policy is proposed.

Rolling Horizon Strategy with Information Sharing

The inefficiency of the supply chain in the previous models is due mostly to the instability of the order amounts faced by the manufacturer in the long run, which causes instable inventory levels, and thus high costs, low service levels and unsatisfied end customers. The cause is probably the extra orders placed by the distributors at the end of each month to fulfill their quota in order to receive the discount option. In the "Monthly Quota" policy, this inefficiency is inevitable, where the total orders of the distributors are checked at the end of each month. This behavior of the distributors, where the order amounts increase at the end of the evaluation period is also called as the "Hockey-Stick Phenomenon" in the literature. A solution to this phenomenon is to base the volume discounts on a rolling horizon basis (Chopra and Meindl, 2004).

In the “Rolling Horizon” policy, the quota fulfillment evaluation is not done at the end of each month, but each time when the order is placed. According to this evaluation, the total amount of orders given in the last thirty days may be compared to the distributor’s individual monthly quota and the volume discount is applied if the quota is fulfilled. Due to the continuous evaluation of the quota fulfillment on the manufacturer’s side, the distributors have to decide on the order amount each time they place an order. This stabilizes the order amounts, lowers the inventory holding costs and increases the customer service levels.

CHAPTER 5

SIMULATION MODELS

To evaluate the performance of the supply chain with its current situation, a discrete event system simulation model is built with a commercial software package ARENA (version: 10.00.00). The data needed to initialize the model's input parameters are stored in the first file of Microsoft Office Excel 2003. After the initialization, the model simulates the supply chain by reading input data from a real-data file, which is the second input file, calculates the values needed to determine the performance measures of the supply chain and write these generated performance measures into a third file, which is then used for output purposes.

During the simulation, the model reads the daily demands of the end customers from the real-data input file and simulates the supply chain accordingly. The output values are calculated as daily cumulatives, and they are used to calculate the resulting costs of inventory holding, purchasing and backordering for each member of the supply chain respectively. Some additional costs that are only applicable to the manufacturer are the transportation cost and the cost of capacity hit that occurs in its warehouse. The revenues, profits, service levels of each member also are evaluated cumulatively during the simulation run. The values calculated for each day of the simulation are recorded in an output file respectively for each member of the supply chain.

Finally, three discrete event simulation models are developed by the commercial software package ARENA, where the first model represents the current situation (Monthly Quota without IS), the second model considers the case where an information system is added to the current model (Monthly Quota with IS), and the third model illustrates the supply chain, where the manufacturer decides on the volume discount option based on a rolling horizon (Rolling horizon with IS).

The input parameters, the output performance measures and the way they are calculated are discussed below in detail.

Input Parameters in the Simulation Model

$InvMan_0$*:* Initial inventory level of the manufacturer.

$InvDistr_n$: Initial inventory level of distributor n, n=1,..,5.

$rDistr_n$: Reorder level (r) of distributor n, n=1,..,5.

$QDistr_n$: Constant order quantity for distributor n, n=1,..,5.

$Quota_n$: Monthly order quota of distributor n, n=1,..,5.

WHCapacity: Warehouse capacity of the manufacturer

$Leadtime_n$: Time needed for transportation from warehouse to distributor n, n=1,..,5.

UnitManCost: Unit manufacturing cost for the manufacturer.

$PurPriceDistr_n$: Unit purchase price for distributor n, n=1,..,5.

$DiscRateDistr_n$: Applicable discount rate for distributor n, n=1,..,5.

$SalePriceDistr_n$: Unit sale price of distributor n, n=1,..,5.

UnitCapacityHitCost: Fixed cost of resetting the manufacturing system.

UnitTrans: Unit transfer cost from the warehouse to the manufacturer.

$FixedCost_n$: Fixed ordering cost faced by distributor n, n=1,..,5.

InterestRate: Daily interest rate in the local currency.

Output Performance Measures in the Simulation Model

RevMan: Total revenue of the manufacturer.

$RevDistr_n$: Total revenue of distributor n, n=1,..,5.

SC_TotalRevenue: Total revenue of the whole supply chain.

CostMan: Total manufacturing cost of the manufacturer.

$CostDistr_n$: Total ordering and purchasing cost of distributor n, n=1,..,5.

SC_TotalOrderCost: Total ordering and purchasing cost of the supply chain.

InvCostMan: Total inventory holding cost of the manufacturer.

$InvCostDistr_n$: Total inventory holding cost of distributor n, n=1,..,5.

SC_TotalInvCost: Total inventory holding cost of the supply chain.

BackOrderCostMan: Total backordering cost of the manufacturer.

$BackOrderCostDistr_n$: Total backordering cost of distributor n, n=1,..,5.

SC_BackOrderCost: Total backordering cost of the supply chain.

CapacityHitCost: Total capacity hit cost of the manufacturer.

TransCostMan: Total transportation cost faced by the manufacturer.

ProfitMan: Total profit of the manufacturer.

$ProfitDistr_n$: Total profit of distributor n, n=1,..,5.

SC_Profit: Total profit of the supply chain.

ServLevelMan: Percentage of demand satisfied on time by the manufacturer.

$ServLevelDistr_n$: Percentage of demand satisfied on time by distributor n, n=1,..,5.

SC_ServLevel: Percentage of demand satisfied on time in the supply chain.

Calculation of Output Performance Measures

Costs and Profit of the Manufacturer

The manufacturer's revenue [RevMan] is increased when the order of a distributor is satisfied. The calculation is done according to the discount rate [DiscRateDistrn] applicable to that distributor, the purchase price of the distributor [PurPriceDistrn] and the amount of the order [OrderQuantityn]. If the distributor fulfills its monthly quota, the discount is applied i.e. DiscRateDistrn > 0; otherwise no discounts are applied and DiscRateDistrn = 0. The revenue of the manufacturer [RevMan] is updated as follows:

$$\text{RevMan} = \text{RevMan} + \left[\text{PurPriceDistr}_n\right]\left[\text{OrderQuantity}_n\right]\left[1 - \text{DiscRateDistr}_n\right].$$

In all models, the daily manufacturing rate [ManufQuantity] is determined by 30-days moving averages. In the first model representing the current configuration of the supply chain (Monthly Quota without IS), the daily manufacturing quantity [ManufQuantity] is forecasted with thirty-days moving averages of the total daily demand of the distributors. In the second model (Monthly Quota with IS) and third model (Rolling Horizon with IS), where the demand information is available on the manufacturer's side, the manufacturing quantity is estimated from the POS data of the distributors by using thirty-days moving averages.

At the end of each day, manufacturing costs are updated by adding the daily manufacturing cost to the previous total. The daily manufacturing cost is calculated by using the daily manufacturing quantity [ManufQuantity] and the unit manufacturing cost [UnitManCost].

$$\text{CostMan} = \text{CostMan} + \left[\text{ManufQuantity}\right]\left[\text{UnitManCost}\right]$$

The capacity of the warehouse is monitored continuously and the manufacturing system is stopped if there is a capacity hit. This incurs a fixed cost of capacity hit, [UnitCapacityHitCost] every time the manufacturing system is stopped. The manufacturing system restarts its process, when the inventory level of the manufacturer falls under 75% of the warehouse capacity.

The total transportation cost [TransCostMan] also is increased according to the unit transportation cost [UnitTrans] and amount of order delivered to the distributor [OrderQuantityn]. According to the agreement between the manufacturer and the distributors, the transportation cost belongs to the manufacturer.

$$\text{TransCostMan} = \text{TransCostMan} + \left[\text{OrderQuantity}_{\text{n}}\right]\left[\text{UnitTrans}\right]$$

At the end of each day, the inventory level of the manufacturer [InvMan] is checked and the total inventory holding cost [InvCostMan] is increased when it has a positive value as:

$$\text{InvCostMan} = \text{InvCostMan} + \left[\text{HoldingCostMan}\right]\left[\text{InvMan}\right].$$

Here, unit inventory holding cost [UnitHoldingCostMan] is an expression showing the opportunity cost of losing the daily interest rate by manufacturing a single unit. It is calculated in the model according to the unit manufacturing cost [UnitManCost] and the daily interest rate [InterestRate] in the local currency. Thus we have,

$$\text{UnitHoldingCostMan} = \left[\text{InterestRate}\right]\left[\text{UnitManCost}\right].$$

When the manufacturer is not able to satisfy the whole order placed by a distributor with its on-hand inventory, the order is fully backordered. The backorder cost [BackOrderCostMan] is calculated and added to the previous total as shown below:

$$\text{BackOrderCostMan} = \text{BackOrderCostMan} + \left[\text{bMan}\right]\left[\text{WaitingOrderQuantity}\right].$$

Where [bMan] is the unit backordering cost for the manufacturer, showing the lost daily interest of the unit profit. Thus it is calculated according to the unit profit of the manufacturer [PurPriceDistrn - UnitManCost] and the daily interest rate [InterestRate] in local currency.

$$\text{bMan} = \left[\text{PurPriceDistr}_n - \text{UnitManCost}\right]\left[\text{InterestRate}\right]$$

The waiting order quantity [WaitingOrderQuantity] is calculated in the simulation model according to the order quantities; those are backordered by the manufacturer. The order quantity of the distributor n is calculated during the simulation according to the ordering policy of the model, which may be “Monthly Quota” or “Rolling Horizon.” In the first and second models, i.e. monthly quota models, at the end of each month, the distributor controls the total order amount placed in that month and give extra orders if necessary to fulfill the monthly quota.

In the third model, where the ordering decisions are made on a rolling horizon basis, this check is made each time when an order will be placed and the order quantity is calculated accordingly. In all cases, if the manufacturer is not able to satisfy an order in a specific time, the distributor cancels its order and gives up the discount if the backordering period is greater than five days.

Finally, the total profit of the manufacturer is calculated as the difference between the total revenue and cost.

$$\text{ProfitMan} = \text{RevMan} - (\text{CostMan} + \text{InvCostMan} + \text{BackOrderCostMan} + \text{TransCostMan} + \text{CapacityHitCost})$$

Costs and Profits of Distributors

The end customers or retailers of the supply chain have a daily demand. In all models it is assumed that the daily demand at any distributor is distributed normally with mean=20 and a standard deviation=0.0001, however this assumption is further analyzed in Chapter 6. The daily demand quantity [DemandQuantityn] of the distributors is read from the MS-Excel file by the simulation model. If its distributor has enough on-hand inventories, it satisfies the whole demand simultaneously. If the inventory level is not enough to satisfy the whole demand, the unsatisfied portion of the demand is backordered. However, the total payments are made at the time of order retrieval and the daily revenue of the distributor [RevDistrn] is updated according to the unit sale price of the distributor [SalePriceDistrn], the daily demand quantity [DemandQuantityn] and added to the previous total as shown below;

$$\text{RevDistr}_n = \text{RevDistr}_n + \left[\text{SalePriceDistr}_n\right]\left[\text{DemandQuantity}_n\right].$$

The total purchasing cost of distributor n [CostDistrn] is the sum of the fixed ordering costs from the manufacturer [FixedCostn] and variable purchasing costs calculated according to the order amount [OrderQuantity] and unit purchase price [PurPriceDistrn] of that individual distributor. If a discount is applicable, the purchasing cost of the distributor is discounted by the discount rate of that distributor [DiscRateDistrn]; otherwise the discount rate is zero. Thus we have,

$$\begin{aligned} \mathrm{CostDistr}_n = {} & \mathrm{CostDistr}_n + \mathrm{FixedCost}_n + \\ & \left[\mathrm{PurPriceDistr}_n\right]\left[(1 - \mathrm{DiscRateDistr}_n)\right]\left[\mathrm{OrderQuantity}_n\right]. \end{aligned}$$

At the end of each day, the distributors' inventory levels [InvDistrn] are checked. The inventory holding cost [InvCostDistrn] is increased if the inventory level is positive as,

$$\mathrm{InvCostDistr}_n = \mathrm{InvCostDistr}_n + \left[\mathrm{InvDistr}_n\right]\left[\mathrm{HoldingCostDistr}_n\right],$$

Here, the unit inventory holding cost [HoldingCostDistrn] is a dynamic expression, showing the daily opportunity cost of holding a single unit in the inventory. It is calculated in the model according to the unit purchasing price [PurPriceDistrn], the daily interest rates [InterestRate] and the discount rate [DiscRateDistrn] as follows:

$$\mathrm{HoldingCostDistr}_n = \left[\mathrm{InterestRate}\right]\left[\mathrm{PurPriceDistr}_n\right]\left[1 - \mathrm{DiscRateDistr}_n\right].$$

The distributor backorders the unsatisfied portion of the retailer's demand as stated before. However, unlike the manufacturer, the distributor can split the orders and the backorder cost of distributor n [BackOrderCostDistrn] increases according to the amount of unsatisfied demand [UnsatisfDemQuantityn] as

$$\text{BackOrderCostDistr}_n = \text{BackOrderCostDistr}_n + \left[\text{UnsatisfDemQuantity}_n\right]\left[b_n\right].$$

Here, the unit backordering cost for distributor n [bn] is a dynamic expression and is calculated in the simulation model according to the unit profit of the distributor [SalePriceDistrn - PurPriceDistrn(1-DiscRateDistrn)] and the daily interest rate [InterestRate],

$$b_n = \left[\text{SalePriceDistr}_n - \text{PurPriceDistr}_n\right]\left[\text{InterestRate}\right]\left[1 - \text{DiscRateDistr}_n\right].$$

Finally, the total profit of distributor n, ProfitDistrn is the difference between the total revenue and the cost,

$$\text{ProfitDistr}_n = \text{RevDistr}_n - (\text{CostDistr}_n + \text{InvCostDistr}_n + \text{BackOrderCostDistr}_n)$$

<u>Costs and Profits of the Supply Chain</u>

The total revenue of the supply chain is calculated by adding the revenues of the manufacturer and all five distributors. Thus the total revenue of the supply chain [SC_TotalRevenue] is:

$$\text{SC\_TotalRevenue} = \text{RevMan} + \sum_{n=1}^{5} \text{RevDistr}_n.$$

Similarly, total inventory holding cost [SC_TotalInvCost], total purchasing cost [SC_TotalOrderCost], and the total backordering cost [SC_BackOrderCost] of the whole supply chain are determined respectively:

$$\text{SC\_TotalInvCost} = \text{InvCostMan} + \sum_{n=1}^{5} \text{InvCostDistr}_n$$

$$\text{SC\_TotalOrderCost} = \text{CostMan} + \sum_{n=1}^{5} \text{CostDistr}_n$$

$$\text{SC\_BackOrderCost} = \text{BackOrderCostMan} + \sum_{n=1}^{5} \text{BackOrderCostDistr}_n$$

Finally, the total supply chain cost [SC_TotalCost] is calculated by adding the total costs of all members of the supply chain; whereas the net total supply chain profit [SC_Profit] are evaluated as,

$$\begin{aligned}\text{SC\_TotalCost} = {} & \text{SC\_TotalInvCost} + \text{SC\_BackOrderCost} + \text{SC\_TotalOrderCost} \\ & + \text{TransCostMan} + \text{CapacityHitCost}\end{aligned}$$

$$\text{SC\_Profit} = \text{ProfitMan} + \sum_{n=1}^{5} \text{ProfitDistr}_n .$$

Other Performance Measures of the Supply Chain

The individual service levels for each member of the supply chain and for the entire supply chain are the common performance measures in supply chain management stated in the literature (Beamon, 1998). It is worthwhile to compare the current model with the proposed models in terms of their percentage of immediate order satisfaction. In application, the definition of order satisfaction might be different for the manufacturer and the distributors, which is accepted as one of the major pitfalls of SCM (Fiala, 2004).

In the supply chain system, order splitting is possible for the orders received by a distributor. When a demand is faced by a distributor, the inventory level is checked. If the on-hand inventory is not enough to satisfy all of the demand, the amount of unsatisfied demand [UnsatisfDemQuantityn] for that distributor is incremented. On the other hand, the quantity of the immediately satisfied demand [SatisfDemQuantityn] is increased by the available quantity on hand. The service level of the distributors is then calculated as the ratio of immediate satisfied demand quantity to total demand:

$$\mathrm{ServLevelDistr}_n = 100\left[\frac{\mathrm{SatisfDemQuantity}_n}{\left(\mathrm{TotalDemand}_n\right)}\right]$$

On the other hand, the manufacturer does not split the order and backorders the whole order when there is not enough on-hand inventory. The distributors wait until the inventory level of the manufacturer is enough to satisfy their order. However, they can only tolerate limited backorder duration; the distributors prefer to cancel their orders and fulfill their demand from other manufacturers. In this case, they cannot use the discount option in the next month if they cannot fulfill their quota. The service level of the manufacturer is measured as the percent immediate satisfaction of the distributors. Both the manufacturer's and the distributors' service levels are calculated respectively as the percent ratio of the immediate fulfilled quantity to the total demand.

$$\text{ServLevelMan} = 100\left[\frac{\text{SatisfDemQuantity}}{\text{TotalDemand}}\right]$$

Finally, the service level of the supply chain is equal to the percent satisfaction of the end-customers of the supply chain; it is measured as the average service levels of the distributors.

$$\text{SC\_ServLevel} = \frac{1}{n}\sum_{i=1}^{n}\text{ServLevelDistr}_i$$

Analysis of the Simulation Models

All three models are run for 360 days (12 months) and replicated fifteen times. In the initial model, the retailer demand data used to simulate the models is hypothetically generated with a normal distribution (with mean=20 and standard deviation=0.0001). To make an accurate comparison between all three models, identical seeds are used in demand data generation and the values of the input parameters needed to initialize the simulation models are given exactly the same.

The hypothetical input values used to initialize the models are given in Table 1. Let us note that inapplicable entries are shown with “X”.

In this example, the monthly quota for each distributor is 450 lots and a 10% discount option exists if the monthly quota is exceeded. The initial inventory levels of each member in the supply chain are taken as their steady state levels to decrease the effect of the warm-up period on the output performance measures.

Table 1. Values of input parameters to initialize simulation models

Input Values For	Manufacturer	Distributor 1	Distributor 2	Distributor 3	Distributor 4	Distributor 5	
Initial Inventory Level	200	60	60	60	60	60	lots
Reorder Level (r)	x	40	40	40	40	40	lots
Fixed Order Quantity (Q)	x	100	100	100	100	100	lots
Monthly Quota	x	450	450	450	450	450	lots
Warehouse Capacity	600	x	x	x	x	x	lots
Lead Time	x	2	2	2	2	2	days
Unit Purchase Price	2,00	5,00	5,00	5,00	5,00	5,00	YTL/lot
Discount Rate	x	0,10	0,10	0,10	0,10	0,10	
Unit Sale Price	x	6,00	6,00	6,00	6,00	6,00	YTL/lot
Unit Transportation Cost	0,2	x	x	x	x	x	YTL/lot
Unit Capacity Hit Cost	1000	x	x	x	x	x	YTL/capacity hit
Fixed Ordering Cost	x	0	0	0	0	0	YTL/order
Daily Interest Rate	0,00033	YTL/YTL/day			1 lot = 1000 units		

According to the output values obtained from the simulation runs, the performance of the supply chain is increased obviously by integrating an information sharing system into the current model. On the other side, the performance of the supply chain is improved further by checking the quotas of the distributors on a rolling horizon basis instead of only at the end of every month. The underlying analyses of these conclusions are described in the next two sections in detail.

The Effect of Information Sharing

Integrating an information sharing system into the current model enables the manufacturer to see the end demand of the supply chain and make better predictions about the future demand.

The comparison related to information sharing may be done by comparing the results of the current model, which uses the “Monthly Quota” strategy without information sharing with the second model that uses the “Monthly Quota” strategy with information sharing. The average values of the performance measures after 15 simulation runs are demonstrated in Table 2 and Table 3, respectively.

It follows from the comparison of the models that, as a result of information sharing, the profits of the supply chain and the manufacturer increase by 45.1% and 74.5%, respectively, whereas the average profit of distributors increases by 16.2%. In addition to that, the service level of the supply chain, which is the percent satisfaction of end-customers, is increased from 94.63% to 97.70% and the service level of the manufacturer is significantly increased from 64.59% to 93.27%.

Due to the more accurate predictions made by the manufacturer, the supply rate is more accurately evaluated, which eliminates the capacity hits faced by the manufacturer in the current system. The capacity hit cost of the manufacturer is significantly decreased by 91.9%, from 37,000,000 YTL to 3,000,000 YTL. Moreover, the backorder and lost sales costs of the manufacturer is decreased significantly by the additional information system. Thus under this input setting, all parties of the supply chain benefit from sharing the demand information across the supply chain members.

A very important result obtained from this analysis is that the difference between the profits of the whole supply chain in the current model and the second model is the “Value of Information Sharing,” which is calculated as 40,233,800 YTL (129,525,890 YTL – 89,292,090 YTL). Significant information is the difference between the profits of the manufacturer in the current and second model, which is the maximum amount that the manufacturer would pay to integrate an information system to share the end-demand data with its distributors. This amount is calculated as 32,924,560 YTL (77,098,920 YTL – 44,174,960 YTL).

To convince the distributors to share the end-demand data, the manufacturer may offer an additional discount option in case, the distributors’ profits are not increased significantly by sharing information. Actually this is not the case in this example, where the distributor profits increase significantly; however, this option is also analyzed in Table 4. Comparison of the results in Table 3 and Table 4 shows that by increasing the discount rate from 10% to 20%, the revenue of the manufacturer is decreased. However, as compared to the current model in Table 2, its profit is still increased by 35.3% from 44,174,260 YTL to 59,775,920 YTL, since the total costs of the manufacturer also are decreased significantly by information sharing. Thus, if the manufacturer offers a 10% additional discount to convince its distributors to share demand information, the maximum amount that should be paid for an information system is decreased to 17,322,900 YTL (59,775,920 YTL – 44,174,260 YTL).

On the other hand, when there is information sharing with a 20% discount rate, the average profit of a distributor is increased from 9,235,640 YTL to 13,941,630 YTL which is 54.5, % as seen in Table 2 and Table 4. Obviously, it is much more attractive than the 10% discount rate for the distributor and still attractive for the manufacturer. Hence, the discount rate should be evaluated by the trade off between the profit changes of the manufacturer and the distributors.

Table 2. Results of monthly quota strategy without IS (discount rate = 0.1)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	372225,00	156225,00	43200,00	43200,00	43200,00	43200,00	43200,00	x 1000 YTL
Inventory Holding Cost	1802,76	454,80	154,94	123,85	553,20	401,34	114,64	x 1000 YTL
Backorder Cost	889,40	80,19	78,62	258,74	25,29	53,08	393,48	x 1000 YTL
Purchasing Cost	236510,75	67785,75	32875,00	32800,00	35175,00	35175,00	32700,00	x 1000 YTL
Transportation Cost	6730,00	6730,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	37000,00	37000,00	x	x	x	x	x	x 1000 YTL
Total Cost	282932,91	112050,74	33108,56	33182,59	35753,49	35629,42	33208,12	x 1000 YTL
Profit	89292,09	44174,26	10091,44	10017,41	7446,51	7570,58	9991,88	x 1000 YTL
Service Levels	94,63	64,59	97,63	91,50	99,44	98,02	86,57	%

Table 3. Results of monthly quota strategy with IS (discount rate = 0.1)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	374925,00	158925,00	43200,00	43200,00	43200,00	43200,00	43200,00	x 1000 YTL
Inventory Holding Cost	1208,41	445,67	158,80	151,92	151,17	151,17	149,69	x 1000 YTL
Backorder Cost	395,70	10,52	297,92	17,47	17,47	17,52	34,80	x 1000 YTL
Purchasing Cost	233725,00	71300,00	32475,00	32500,00	32500,00	32500,00	32450,00	x 1000 YTL
Transportation Cost	7070,00	7070,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	3000,00	3000,00	x	x	x	x	x	x 1000 YTL
Total Cost	245399,11	81826,18	32931,71	32669,39	32668,65	32668,70	32634,49	x 1000 YTL
Profit	129525,89	77098,82	10268,29	10530,61	10531,35	10531,30	10565,51	x 1000 YTL
Service Levels	97,79	93,27	90,36	99,72	99,72	99,72	99,44	%

Table 4. Results of monthly quota strategy with IS (discount rate = 0.2)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	357600,00	141600,00	43200,00	43200,00	43200,00	43200,00	43200,00	x 1000 YTL
Inventory Holding Cost	1125,04	445,67	142,53	135,04	134,38	134,38	133,06	x 1000 YTL
Backorder Cost	520,92	8,42	396,15	23,30	23,30	23,36	46,40	x 1000 YTL
Purchasing Cost	216400,00	71300,00	29200,00	29000,00	29000,00	29000,00	28900,00	x 1000 YTL
Transportation Cost	7070,00	7070,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	3000,00	3000,00	x	x	x	x	x	x 1000 YTL
Total Cost	228115,96	81824,08	29738,68	29158,33	29157,67	29157,74	29079,45	x 1000 YTL
Profit	129484,04	59775,92	13461,32	14041,67	14042,33	14042,26	14120,55	x 1000 YTL
Service Levels	97,79	93,27	90,36	99,72	99,72	99,72	99,44	%

Effect of the Rolling Horizon Strategy

In the second model, the current model is enhanced by integrating an information sharing system; however, in both models the orders are significantly greater at the end of the month.

In the third model monthly quota, checks are performed on a rolling horizon basis, i.e. every time an order is placed by the distributor, instead of at the end of month only. The inventory levels of each policy applied are animated in the simulation model and illustrated in Figure 4.

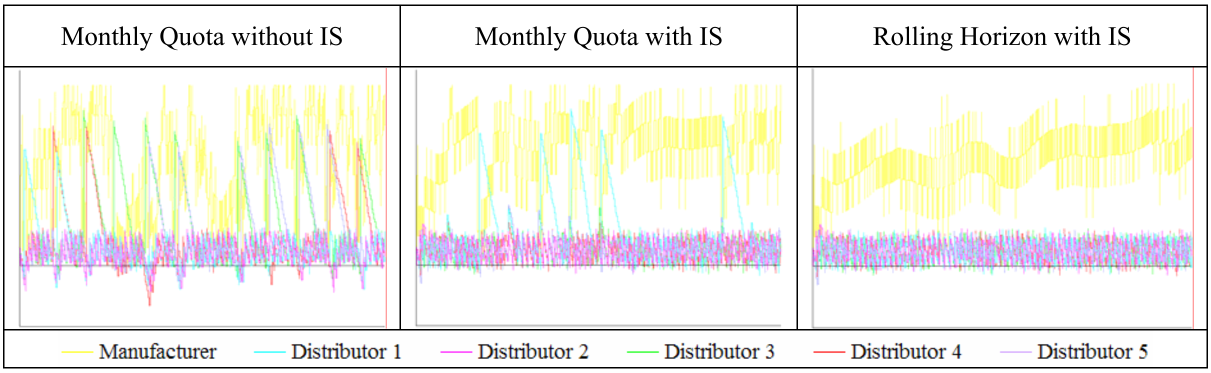


Figure 4. Inventory levels of the supply chain members.

It follows that the backorders are more frequent in the “Monthly Quota” policy without information sharing. Information sharing decreases the backorder levels as seen in the second model; however, the “Rolling Horizon” strategy further improves the system by decreasing capacity hits and end-of-month order accumulation at the manufacturer.

According to the output performance measures obtained from the simulation runs of the third model in Table 5, the performance of the supply chain is significantly improved by applying the “Rolling Horizon” policy.

Table 5. Results of rolling horizon strategy with IS (discount rate = 0,1)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	378750,00	162750,00	43200,00	43200,00	43200,00	43200,00	43200,00	x 1000 YTL
Inventory Holding Cost	859,95	212,19	175,99	117,69	117,69	117,69	118,68	x 1000 YTL
Backorder Cost	2,97	2,97	0,00	0,00	0,00	0,00	0,00	x 1000 YTL
Purchasing Cost	235250,00	72000,00	32650,00	32650,00	32650,00	32650,00	32650,00	x 1000 YTL
Transportation Cost	7180,00	7180,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	0,00	0,00	x	x	x	x	x	x 1000 YTL
Total Cost	243292,92	79395,16	32825,99	32767,69	32767,69	32767,69	32768,68	x 1000 YTL
Profit	135457,08	83354,84	10374,01	10432,31	10432,31	10432,31	10431,32	x 1000 YTL
Service Levels	100,00	98,36	100,00	100,00	100,00	100,00	100,00	%

The models are evaluated by comparing the results obtained from the current "Monthly Quota" model where there is information sharing and the "Rolling Horizon" model. It follows from the results in Table 3 and Table 5 that, by the inclusion of the "Rolling Horizon" strategy, the profits of the supply chain and the manufacturer are increased further by 4.6% and 8.1%, respectively, whereas the average profits of the distributors are decreased by 0.6%.

Due to the decreased inventory levels in the supply chain, the inventory holding costs of the supply chain and manufacturer are decreased by 28.8% and 58.4%, respectively. Similarly the average inventory holding costs of the distributors decrease by 15.1%. Since the inventory level of the manufacturer becomes very stable by applying the "Rolling Horizon" policy, there is not any warehouse capacity hit in this model.

In the "Rolling Horizon with IS" model, the distributors do not need to cancel their orders and give up the discount, because the backordering periods never exceed five days. This is followed by 71.8% decrease in the backordering cost of the manufacturer and 5.5% increase in the percent satisfaction of the distributors from the manufacturer. The service levels of the distributors, i.e., the percent satisfaction of the end-customers of the supply chain reach a value of 100%, which means almost no backordering cost for distributors. Since the end-customer is the only party who feeds cash into the supply chain, this satisfaction is the ultimate goal in the long-run.

On the distributors' side, the benefits obtained by the "Rolling Horizon" strategy are not very significant. One of the distributors gets slightly better profits whereas four of them get lower profits. The reasoning lies behind the fact that in the "Rolling Horizon" policy, the distributor is able to purchase more in a stable manner since the customer satisfaction level for the manufacturer gets very high. This increases the purchase costs and decreases the backorder costs plus inventory holding costs for the distributor. However, these cost changes are not significant since the distributor already has a high service level in the "Monthly Quota with IS" model. Furthermore, his revenue is not affected since the distributor receives the order payments at the time of order arrival even when the order gets into backorder.

As a result, under this input setting, the "Rolling Horizon with IS" policy seems to improve the profits and service level of the manufacturer very significantly whereas it does not incorporate a significant improvement to the distributors.

CHAPTER 6

EXPERIMENTAL DESIGN

In this study, the experiments are designed to run three different models, under different settings for different input parameters. The first variable of the experimental design is the "policy applied," which can take three different values, as given in Table 6. The first policy represents the current situation, where a "Monthly Quota" strategy is applied between the manufacturer and the distributors without any information sharing among the supply chain. The second policy stands for the same volume discount option strategy, namely "Monthly Quota," but in this model, an information system is applied to the supply chain, which enables the manufacturer to see the end customer demand by collecting the POS data of its distributors. The third policy illustrates the use of deciding the volume discount option, based on a "Rolling Horizon" strategy.

The "demand variability" of the end customers of the supply chain is selected to be the second variable in the experimental design, because the value of information sharing highly depends on the variability of the end customer demand that increases the "Bullwhip Effect." The demand variability is described as the %

ratio of the standard deviation to the mean. The demand variability takes four different values as 0%, 25%, 50% and 75% of the mean, respectively, as given in Table 7.

The third variable in the experimental design is selected to be the "discount rate" offered to the distributors by the manufacturer, because the discount rate has a significant effect on the revenues, costs and thus profits of all individual members of the supply chain. The discount rate takes three different values 10%, 20% and 30%, as given in Table 8.

Finally, the variables of the experimental design are:

Table 6. Variable A in experimental design

Variable A	Policy Applied
1	Monthly Quota - without information sharing
2	Monthly Quota - with information sharing
3	Rolling Horizon – with information sharing

Table 7. Variable B in experimental design

Variable B	Demand Variability (% ratio of standard deviation to the mean)
1	0,00005%
2	25%
3	50%
4	75%

Table 8. Variable C in experimental design

Variable C	Discount Rate
1	10%
2	20%
3	30%

In the design of experiments, 36 cases are formed by considering all possible combinations of these three variables, as shown in Table 9.

Table 9. Cases in the experimental design

Case No	Variable C	Variable B	Variable A
1	C1	B1	A1
2	C1	B1	A2
3	C1	B1	A3
4	C1	B2	A1
5	C1	B2	A2
6	C1	B2	A3
7	C1	B3	A1
8	C1	B3	A2
9	C1	B3	A3
10	C1	B4	A1
11	C1	B4	A2
12	C1	B4	A3
13	C2	B1	A1
14	C2	B1	A2
15	C2	B1	A3
16	C2	B2	A1
17	C2	B2	A2
18	C2	B2	A3
19	C2	B3	A1
20	C2	B3	A2
21	C2	B3	A3
22	C2	B4	A1
23	C2	B4	A2
24	C2	B4	A3
25	C3	B1	A1
26	C3	B1	A2
27	C3	B1	A3
28	C3	B2	A1
29	C3	B2	A2
30	C3	B2	A3
31	C3	B3	A1
32	C3	B3	A2
33	C3	B3	A3
34	C3	B4	A1
35	C3	B4	A2
36	C3	B4	A3

The Analysis of the Design of Experiments

The analysis and comparison of the experiments are done according to the five important performance measures of the supply chain, namely the profit of the supply chain, the profit of the manufacturer, the average profit of the distributors, the service level of the supply chain and the service level of the manufacturer.

For each performance measure 95% confidence intervals are estimated by the formula,

$$\% \text{ 95 confidence interval} = \overline{x} \pm t_{n-1,\frac{\alpha}{2}} \frac{s}{\sqrt{n}}$$

Where, n=15 and α =0.05. Here "$\overline{x}$" is the average value of the performance measure obtained after 15 runs and, "s" is the standard deviation calculated as,

$$\overline{x} = \left(\frac{\sum_{i=1}^{n} x_i}{n} \right),$$

$$s = \sqrt{\sum_{i=1}^{n} \frac{\left(x_i - \overline{x}\right)}{\left(n-1\right)}}.$$

The estimations are tabulated in terms of the average values and the percent relative errors where,

$$\% \text{ relative error} = \frac{t_{n-1,\frac{\alpha}{2}} \frac{s}{\sqrt{n}}}{\overline{x}}.$$

The results of 36 cases are tabulated with their averages $\pm$ percent relative errors. Table 10 includes the cases of C1 where the discount rate is 10%; Table 11 includes the cases of C2, where the discount rate is 20%; and Table 12 includes the cases of C3, where the discount rate is 30%. It can be seen that the percent relative errors are mostly less than 5% and the highest values is 20% after 15 runs.

Table 10. Results of experiments for the discount rate 10% (C1 case)

Results For C1	Variable B	Variable A	Supply Chain Profit	Manufacturer Profit	Average Distributor Profit	Service Level of Supply Chain	Service Level of Manufacturer
Case 1	B1	A1	89292,09 ± 0,00 %	44174,26 ± 0,00%	9023,57 ± 0,00%	94,63 ± 0,00%	64,59 ± 0,00%
Case 2	B1	A2	129525,89 ± 0,00%	77098,82 ± 0,00%	10485,41 ± 0,00%	97,79 ± 0,00%	93,27 ± 0,00%
Case 3	B1	A3	135457,08 ± 0,00%	83354,84 ± 0,00%	10420,45 ± 0,00%	100,00 ± 0,00%	98,36 ± 0,00%
Case 4	B2	A1	114422,58 ± 3,23%	68380,33 ± 5,04%	9208,45 ± 4,13%	91,84 ± 0,61%	70,81 ± 2,35%
Case 5	B2	A2	118966,25 ± 1,34%	69839,84 ± 2,26%	9825,28 ± 1,80%	94,64 ± 0,27%	80,49 ± 2,18%
Case 6	B2	A3	134300,29 ± 0,37%	82288,61 ± 0,48%	10402,34 ± 0,43%	94,64 ± 0,20%	98,02 ± 0,44%
Case 7	B3	A1	116164,32 ± 2,07%	69806,03 ± 2,91%	9271,66 ± 2,49%	90,39 ± 1,02%	71,89 ± 2,49%
Case 8	B3	A2	117404,68 ± 1,55%	68881,24 ± 1,97%	9704,69 ± 1,76%	92,43 ± 0,38%	78,29 ± 2,16%
Case 9	B3	A3	133841,30 ± 0,76%	81926,55 ± 0,84%	10382,95 ± 0,80%	92,22 ± 0,19%	96,68 ± 0,49%
Case 10	B4	A1	116885,47 ± 3,15%	69736,46 ± 4,03%	9429,80 ± 3,59%	70,52 ± 19,98%	63,83 ± 6,61%
Case 11	B4	A2	121218,10 ± 1,89%	71954,51 ± 2,67%	9852,72 ± 2,28%	88,71 ± 0,46%	77,19 ± 2,41%
Case 12	B4	A3	137429,38 ± 0,97%	84270,19 ± 1,22%	10631,84 ± 1,10%	88,22 ± 0,41%	95,14 ± 0,74%

Table 11. Results of experiments for the discount rate 20% (C2 case)

Results For C2	Variable B	Variable A	Supply Chain Profit%	Manufacturer Profit%	Average Distributor Profit%	Service Level of Supply Chain%	Service Level of Manufacturer %
Case 13	B1	A1	89108,92 ± 0,00%	33660,40 ± 0,00%	11089,70 ± 0,00%	94,63 ± 0,00%	64,59 ± 0,00%
Case 14	B1	A2	129484,04 ± 0,00%	59775,92 ± 0,00%	13941,62 ± 0,00%	97,79 ± 0,00%	93,27 ± 0,00%
Case 15	B1	A3	135463,72 ± 0,00%	66604,84 ± 0,00%	13771,78 ± 0,00%	100,00 ± 0,00%	98,36 ± 0,00%
Case 16	B2	A1	114084,09 ± 3,24%	55863,10 ± 5,80%	11644,20 ± 4,52%	91,84 ± 0,61%	70,81 ± 2,35%
Case 17	B2	A2	118762,65 ± 1,34%	54991,29 ± 2,93%	12754,27 ± 2,14%	94,64 ± 0,27%	80,49 ± 2,18%
Case 18	B2	A3	134251,66 ± 0,38%	65568,75 ± 0,52%	13736,58 ± 0,45%	94,64 ± 0,20%	98,02 ± 0,44%
Case 19	B3	A1	115755,98 ± 2,10%	57038,28 ± 3,38%	11743,54 ± 2,74%	90,39 ± 1,02%	71,89 ± 2,49%
Case 20	B3	A2	117112,88 ± 1,55%	54477,95 ± 2,22%	12526,99 ± 1,89%	92,43 ± 0,38%	78,29 ± 2,16%
Case 21	B3	A3	133767,73 ± 0,76%	65313,63 ± 0,87%	13690,82 ± 0,81%	92,22 ± 0,19%	96,68 ± 0,49%
Case 22	B4	A1	115578,20 ± 2,89%	56231,15 ± 4,13%	11869,41 ± 3,51%	70,52 ± 19,98%	63,83 ± 6,61%
Case 23	B4	A2	120726,52 ± 1,89%	57470,24 ± 3,17%	12651,26 ± 2,53%	88,71 ± 0,46%	77,19 ± 2,41%
Case 24	B4	A3	137306,72 ± 0,97%	67291,22 ± 1,36%	14003,10 ± 1,17%	88,22 ± 0,41%	95,14 ± 0,74%

Table 12. Results of experiments for the discount rate 30% (C3 case)

Results For C3	Variable B	Variable A	Supply Chain Profit%	Manufacturer Profit%	Average Distributor Profit%	Service Level of Supply Chain%	Service Level of Manufacturer %
Case 25	B1	A1	88925,74 ± 0,00%	23146,54 ± 0,00%	13155,84 ± 0,00%	94,63 ± 0,00%	64,59 ± 0,00%
Case 26	B1	A2	129442,20 ± 0,00%	42453,02 ± 0,00%	17397,83 ± 0,00%	97,79 ± 0,00%	93,27 ± 0,00%
Case 27	B1	A3	135470,35 ± 0,00%	49854,84 ± 0,00%	17123,10 ± 0,00%	100,00 ± 0,00%	98,36 ± 0,00%
Case 28	B2	A1	113745,60 ± 3,25%	43345,87 ± 7,11%	14079,95 ± 5,18%	91,84 ± 0,61%	70,81 ± 2,35%
Case 29	B2	A2	118559,05 ± 1,34%	40142,75 ± 4,24%	15683,26 ± 2,79%	94,64 ± 0,27%	80,49 ± 2,18%
Case 30	B2	A3	134203,04 ± 0,38%	48848,89 ± 0,60%	17070,83 ± 0,49%	94,64 ± 0,20%	98,02 ± 0,44%
Case 31	B3	A1	115347,65 ± 2,13%	44270,53 ± 4,27%	14215,42 ± 3,20%	90,39 ± 1,02%	71,89 ± 2,49%
Case 32	B3	A2	116821,09 ± 1,55%	40074,65 ± 3,09%	15349,29 ± 2,32%	92,43 ± 0,38%	78,29 ± 2,16%
Case 33	B3	A3	133694,17 ± 0,76%	48700,71 ± 0,92%	16998,69 ± 0,84%	92,22 ± 0,19%	96,68 ± 0,49%
Case 34	B4	A1	114270,94 ± 2,75%	42725,83 ± 5,96%	14309,02 ± 4,35%	70,52 ± 19,98%	63,83 ± 6,61%
Case 35	B4	A2	120234,94 ± 1,88%	42985,98 ± 4,45%	15449,79 ± 3,17%	88,71 ± 0,46%	77,19 ± 2,41%
Case 36	B4	A3	137184,06 ± 0,97%	50312,24 ± 1,61%	17374,36 ± 1,29%	88,22 ± 0,41%	95,14 ± 0,74%

Now we analyze all three variables in terms of four different performance measures, namely the supply chain profit, the manufacturer profit, the average distributor profit, the service level of the manufacturer and the supply chain.

Supply Chain Profit

Analysis of the supply chain profits yields that, the highest profit is reached with the "Rolling Horizon" policy at all demand variability levels for a given discount rate as seen in Figure 5. Furthermore the "Monthly Quota with IS" policy yields to higher profits for the supply chain than the current policy, "Monthly Quota without IS".

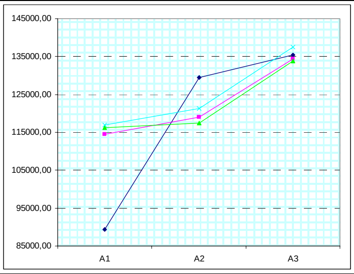
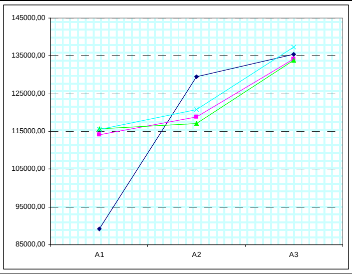
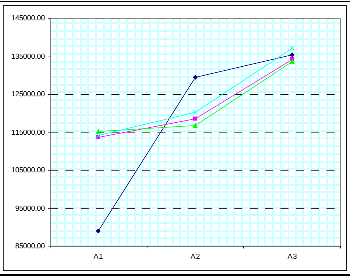
For C1 (Discount Rate = 10%)	For C2 (Discount Rate = 20%)	For C3 (Discount Rate = 30%)
		
$(s/\overline{x})$ is represented with 0% 25% 50% 75%		

Figure 5. Supply chain profit versus policy applied.

By comparing the three graphs in Figure 5, we can see that the "discount rate" does not have a significant effect on this conclusion as expectedly. The increase in the discount rate decreases the manufacturer revenue while increasing the purchase costs of the distributors with the same amount. Furthermore, due to the increases in the discount rate, the unit backorder costs of the distributors increase while the unit backorder costs of the manufacturer decrease, as demonstrated in case 1 & case 13 in the Appendix. In the overall, a change in the discount rate does not significantly affect the supply chain profit for any given policy.

Finally, it is observed that the "demand variability" affects the supply chain profits in different ways for different policies. In the current "Monthly Quota without IS" model, supply chain profits increase as the demand variability increases, as seen in Figure 6. In the second “Monthly Quota with IS” model and third “Rolling Horizon with IS” model, the supply chain profit is higher for very low and high demand variabilities, whereas it is lower for moderate demand variability levels. The reasoning lies behind the fact that in the “Monthly Quota without IS” model, the manufacturing rate is determined by taking the 30-days moving averages of the sales data to the distributors. This data has a very high variance since there are no orders for several days and end-of-month orders are very high. High variability in sales data leads to high forecasting errors for the manufacturer, which in turn results in frequent capacity hits. Noting that in this continuous system the fixed cost of capacity hit is very high, high forecasting errors are followed by low supply chain profits. On the other hand, as the demand variability increases, the possibility of facing zero orders per day decreases for the manufacturer. As a result, the variability in sales and thus the forecasting errors are relatively lower, which results in lower capacity hit costs and higher supply chain profits.

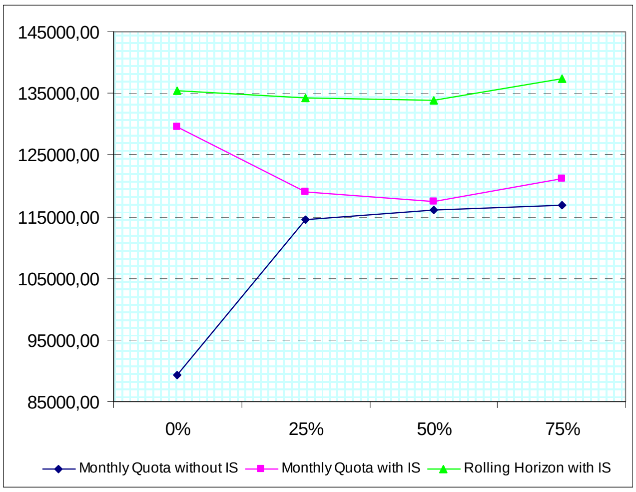


Figure 6. Supply chain profit versus demand variability (discount rate=10%)

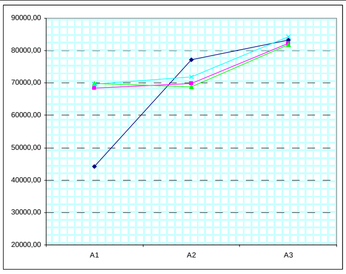
On the other hand, when there is information sharing in the supply chain system, the manufacturer decides on its manufacturing rate by using the end-demand data and thus the forecast errors are lower than the “Monthly Quota without IS” policy. This obviously results in higher supply chain profits. As the demand variability increases, so do the forecasts errors that lead to lower supply chain profits. However, when the demand variability is very high, there is a slight increase in supply chain profits, though it is not a significant increase at the 95% confidence level. The reasoning lies behind the fact that the average daily demand is increased due to the increase in the number of the truncations of negative values in demand data generation. Thus the revenue of the supply chain is increased slightly, which also results in a slight increase in the supply chain profits.

Manufacturer Profit

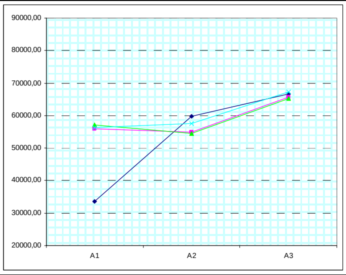
Similar results are obtained for the profit of the manufacturer under different policies applied with different demand variability and discount rates. The change in manufacturer profits is given in Figure 7. When the discount rate is 10%, the profit of the manufacturer increases if the demand information is shared. In addition to this, the manufacturer profit is increased further by applying the "Rolling Horizon" policy. On the other hand, for the discount rates 20% and 30%, the information sharing in the monthly quota strategy slightly decreases the manufacturer profit unless the demand variability is zero. However, the "Rolling Horizon" policy still gives the highest manufacturer profit at all demand variability levels.

Next, by using the three graphs in Figure 7, we try to explain the effect of "discount rate" with the following argument: For a fixed policy and demand variability, the manufacturer profit naturally decreases, when the discount rate is increased since the unit sale price and thus the revenue of the manufacturer decreases. This can be followed through the tables demonstrated in case 1, case 13 and case 25 in the Appendix, for discount rates 10%, 20% and 30%, respectively.

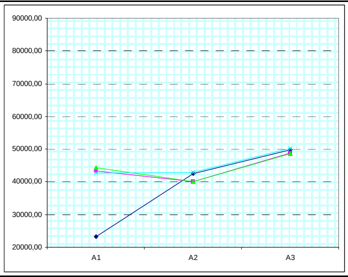
For C1
(Discount Rate = 10%)



For C2
(Discount Rate = 20%)



For C3
(Discount Rate = 30%)



$(s/\bar{x})$ is represented with

0% 25% 50% 75%

Figure 7. Manufacturer profit versus policy applied.

In the analysis of the effect of "demand variability," it is observed that it affects the manufacturer profit in different ways for different policies. By using the similar arguments in the analysis of supply chain profits, in the current "Monthly Quota without IS" policy, the manufacturer profit increases with increasing demand variability, as seen in Figure 8. In this policy, by increasing the demand variability from 50% to 75%, the manufacturer profit faces a slight decrease, which is statistically insignificant at the 95% confidence level. In the second "Monthly Quota with IS" model and third "Rolling Horizon with IS" model, the manufacturer profits are lower for the moderate level of demand variability, as seen in Figure 8. The same arguments given in the analysis of supply chain profits are used to explain the change in the manufacturer profit: The forecasting errors and thus the frequency of the capacity hits of the manufacturer are relatively lower at higher demand variability levels, so the manufacturer profits are higher for higher demand variabilities. However, similar to the supply chain profits analysis, when the demand variability is very high, there is a slight increase in supply chain profits. The same arguments expressed in the former analysis for supply chain profits is valid for the reasoning of this fact.

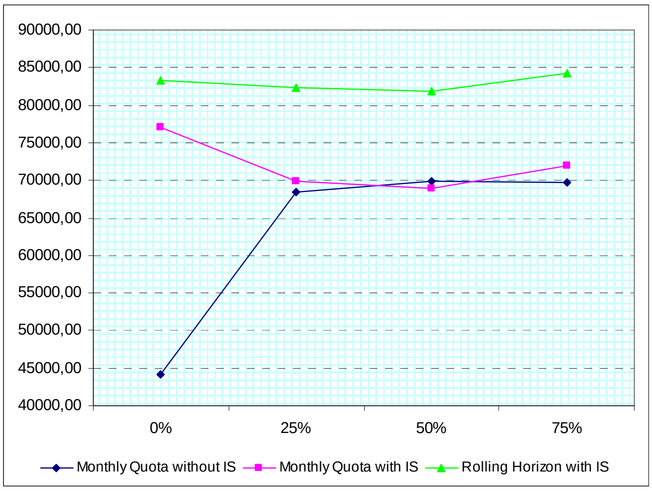


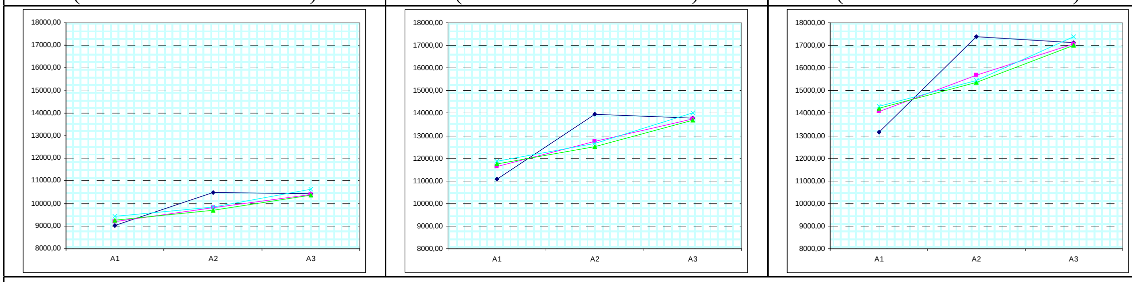
Figure 8. Manufacturer profit versus demand variability (discount rate=10%).

Distributor Profit

The average profits of distributors are analyzed under different policies and different demand variabilities for all cases of discount rates. A conclusion drawn from the results of the analyses in Figure 9 is that in the second and third policies, the average profits of the distributors has an increasing trend, except for the case of nearly constant demand. In the case of constant demand (A1), the integration of an information system improves the average distributor profit; however, the "Rolling Horizon" policy does not influence the average profit of the distributors positively with respect to the second "Monthly Quota with IS" policy. However, it is still greater than the current system. The reasoning lies behind the fact that the "Rolling Horizon" is a strategy forced by the manufacturer to stabilize its inventory levels by eliminating the extra end-of-month orders placed by the distributors and thus decrease the high inventory holding costs. The benefits are apparent in the manufacturer profits; however, the profit share of distributor is lower.

It follows from the three graphs in Figure 9 that the average distributors' profit increases with increasing "discount rates." Since the unit purchasing cost and the unit inventory holding cost of the distributors are decreased, the total costs of the distributors are decreased significantly, while the revenue and all other costs remain constant as demonstrated in case 1, case 13 and case 25 in the Appendix for the discount rates of 10%, 20% and 30%, respectively. There is a slight increase in the unit backorder cost though the overall effect is not significant.

For C1 (Discount Rate = 10%)	For C2 (Discount Rate = 20%)	For C3 (Discount Rate = 30%)



($s/\overline{x}$) is represented with

0% 25% 50% 75%

Figure 9. Average distributor profit versus policy applied.

In the analysis of the effect of the demand variability, similar results are obtained as in the analysis of supply chain and the manufacturer profits. In the current system, the average profit of the distributors is increased with increasing demand variabilities, whereas in the second and the third model, it is decreased for moderate demand variabilities and slightly increased for very high demand variability levels, as seen in Figure 10.

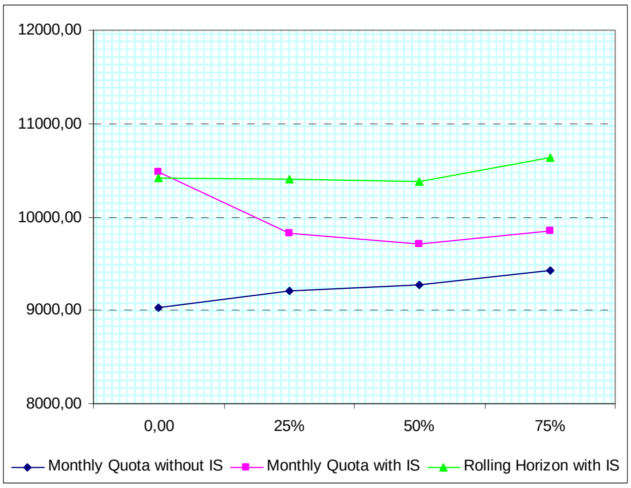


Figure 10. Average distributor profit versus demand variability (discount rate=10%)

Service Levels of the Supply Chain and the Manufacturer

The service level of the supply chain is equal to the percent satisfaction of the end-customers of the supply chain; it is measured as the average service levels of the distributors, whereas the service level of the manufacturer is measured as the percent satisfaction of the distributors.

The service levels of the supply chain and the manufacturer are independent of the "discount rates", as can be followed from the case 1, case 13 and case 25 in the Appendix, so the discount rate is not an effective variable in this analysis.

The results of the analyses are shown in Figure 11. For a fixed level of demand variability, the service levels of the supply chain and the manufacturer increase in the second and third models where there is information sharing. In the second "Monthly Quota with IS" policy and third "Rolling Horizon" policy, the distributors cancel their orders less frequently due to the higher availability of the manufacturer in these policies. This obviously results in higher service levels both for the supply chain and the manufacturer. However, it should be noted that the

“Monthly Quota with IS” and “Rolling Horizon with IS” policies bring higher service level improvements to the manufacturer than the overall supply chain.

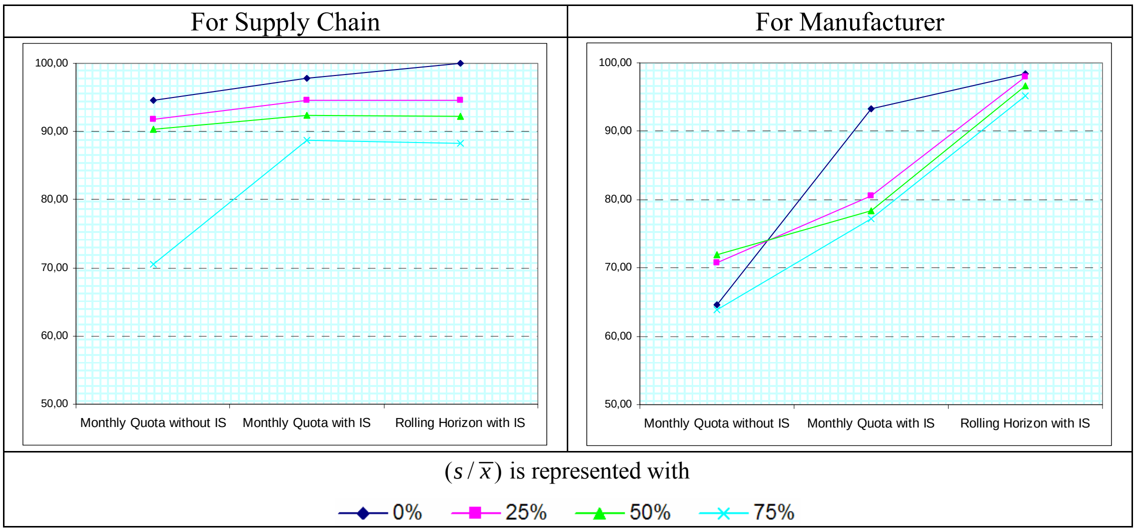


Figure 11. Service levels for different policies applied.

In the analysis of the effect of “demand variability” on the supply chain service levels, it is observed in the first graph of Figure 12 that for any given policy, the service levels of the supply chain decrease with increasing demand variability as expectedly. However, as seen in the second graph of Figure 12, in the “Monthly Quota with IS” model, the service level of the manufacturer increases as the demand variability is increased. Moreover, the service level of the manufacturer is decreased in very high demand variability. This is due to the fact that the forecasting errors of the manufacturer are relatively higher in low demand variabilities, as expressed in the analysis of the profits of the supply chain members in the former sections. However, in the second and the third models, the service level of the manufacturer decreases with increasing demand variability levels, as can be seen in the second graph of Figure 12, so the demand variability affects the service level of the manufacturer as expected.

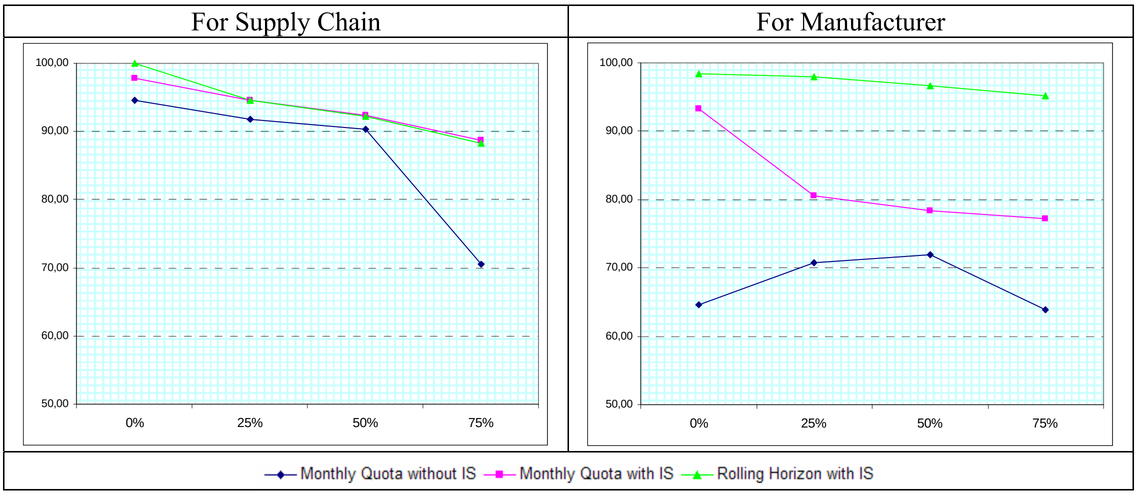


Figure 12. Service levels versus demand variability.

CHAPTER 7

DECISION SUPPORT SYSTEM ENVIRONMENT

A Decision Support System (DSS) is a management information system (MIS) that can facilitate decision-making among senior managers. It emphasizes change and reinforces flexibility, rapid response and robustness using models and assumptions, and consolidates necessary information by displaying meaningful summary reports and graphics. This information system combines data, model and sensitivity analysis to support semi-structured and unstructured decision-making processes at the management level of an organization. Supporting the decision-making activities of an organization with an information system provides improved preplanning, increased participation, criticism-free idea generation and evaluation objectivity. In addition, it analyses, compares and highlights trends, speeds up decision-making, improves management performance, increases management's span of control and better monitoring of activities.

In this study, a simulation-model driven DSS is developed to perform powerful sensitivity analysis in a supply chain. To determine the impact of change in the supply chain model, what-if questions may be asked repeatedly. The structural overview of the generated DSS is demonstrated in Figure 13. The basic components of the DSS Framework are the database, graphical user interface and the simulation model, which are discussed below in detail.

Database: It covers the input data needed and the output data provided in the system. In this study, Microsoft Office Excel 2003 environment is preferred for these purposes. Two different input files are utilized: the first one is to give the values of input parameters needed to initialize the system and is also used by the graphical user interface. The second input file contains the data of the Transaction Processing System (TPS), which includes the values of end-demand for each distributor. The data in the output file is generated by the simulation model during the run.

Graphical User Interface: Since the interaction with the system will be done by senior managers, an easy to use interface is important. The generated environment in this study fulfills this requirement. The values of all input parameters may be changed through a consolidated table and the system may begin to simulate the supply chain model by clicking a button. The entered values are manipulated by the model to obtains the values of the output performance measures, which are then displayed both with graphics and a consolidated table as a summary report in the same screen. The user interface that provides interaction between the MS-Excel and ARENA environments is developed by the Visual Basic programming language.

Model: A model is the abstract representation of the system illustrating components and relationships. To evaluate the difference between the three different models, three different discrete event system simulation models are developed with a commercial simulation software package, ARENA (version: 10.00.00). To determine the impact of change in the input values on the model, these simulation models may be accessed via the user-interface. The supply chain managers may analyze their supply chain system by repeating what-if questions on the model.

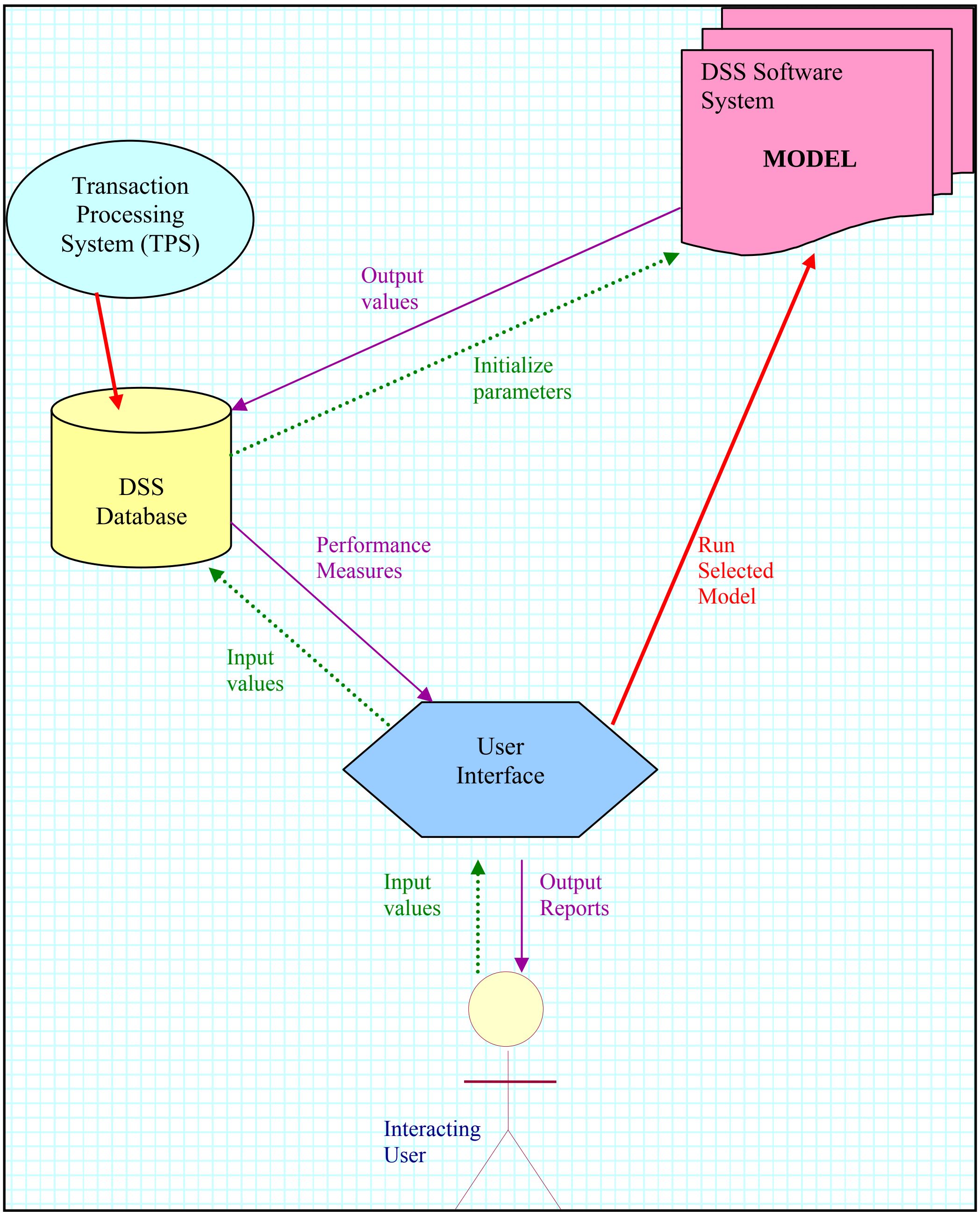


Figure 13. Decision support system framework

Illustrative Example

The decision support system environment generated in this study is developed with Microsoft Visual Basic 6.0 and given the name "ProdSIM". The system is integrated both with Microsoft Excel for the input and output purposes, and with ARENA in order to run the simulation models for evaluating the performances of different systems.

An example is given below to illustrate the flow of activities in ProdSIM.

When the end-user runs the ProdSIM software, a screen with a button appears enabling the user to enter the system and to get to the user interface, as seen in Figure 14:

Figure 14. Initial screen of the DSS environment

The user interface screen in Figure 15 is used to check the input values for the default configuration. The user is able to update the input values here. The system automatically checks the consistency of the values and prevents the user from entering invalid data. For example, after setting the input parameters, the system controls whether the given value is alphanumeric or not. If an error is encountered, the system automatically replaces the entered alphanumeric value with the last correct value set, and warns the user with an information message that the system only accepts numerical input values. The user always is able to leave ProdSIM by clicking the "Exit" button located on the bottom-left side of the interface screen.

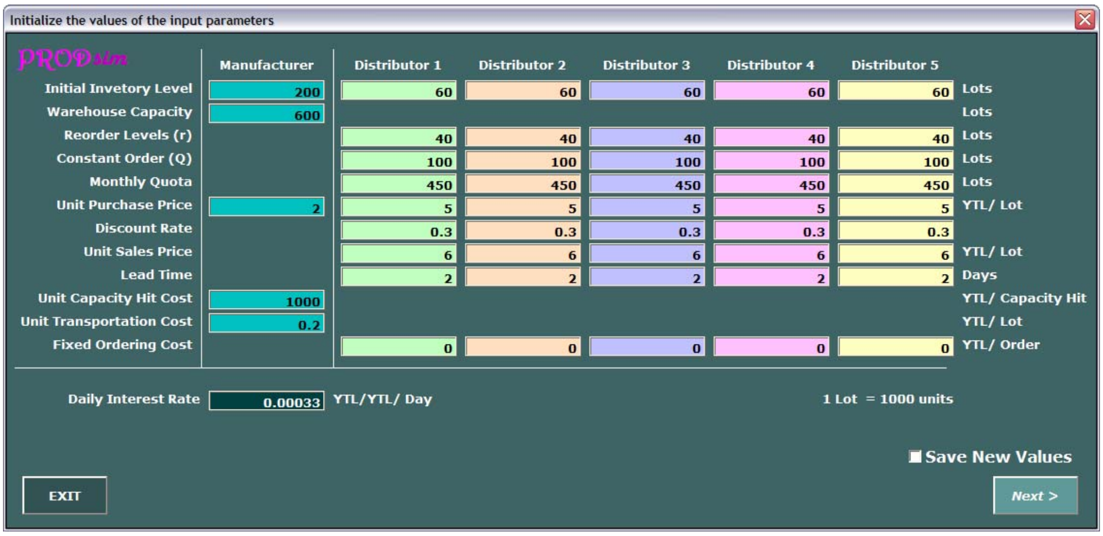


Figure 15. Screen to initialize the values of input parameters

The user is able to change all the input values on this screen and save the settings by clicking the check box on the bottom-right side of the screen with the label "Save New Values." If this check box is checked and the user tries to pass to the next screen by clicking the "Next" button, there exists one more system check. The user interface displays a message, and confirms the saving of the new input values, as seen in Figure 16.

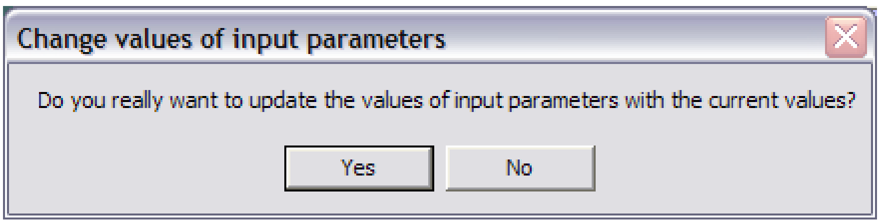


Figure 16. Dialog box to save input values

If the user continues with the "Yes" option, then the changed values are set; otherwise, the system continues with the last saved input values by automatically replacing the values to its default ones, and displays the information message shown in Figure 17:

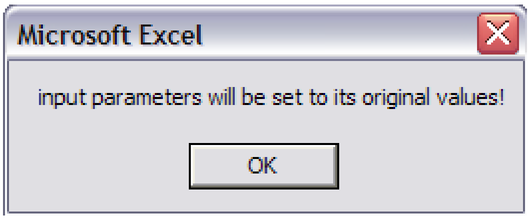


Figure 17. Dialog box to set original values

The user also is able to exit ProdSIM on this screen by clicking the “Exit” button on the bottom-left side of the screen, as can be followed in Figure 15.

After clicking the “Next” button, a screen for “Model Selection” appears, as in Figure 18, enabling the user to select the model to run with the given input parameters;

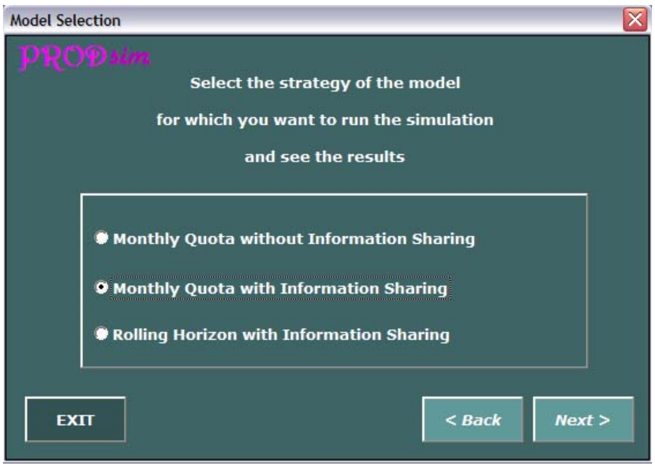


Figure 18. Screen to select the simulation model to run

The user has three options: (i) leaving ProdSIM by clicking the “Exit” button, (ii) returning to the previous screen by clicking the “Back” button, and (iii) further interacting with the system by choosing the model to run and clicking the “Next” button.

When the user proceeds with the "Next" button, the system starts to communicate with the simulation software, ARENA, and triggers the selected model to progress into the running state.

During the simulation, ProdSIM displays a warning screen with the title "Simulating" and notifies the user to wait, as seen in Figure 19.

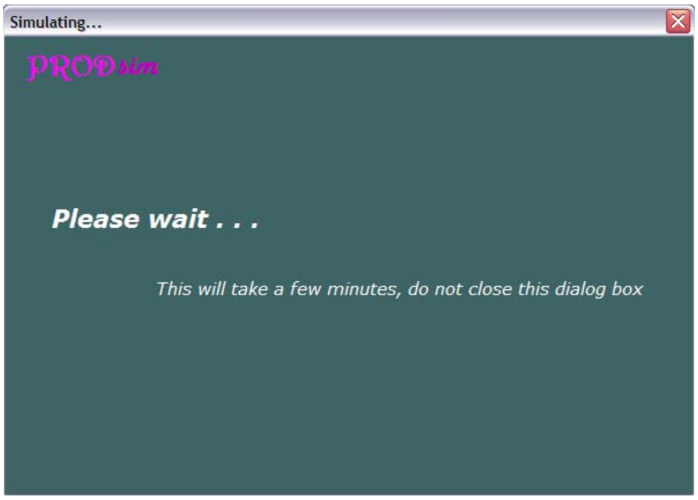


Figure 19. Screen for waiting the simulation completion

After the simulation is completed, the system automatically displays the "Results of the simulation" screen in Figure 20, showing the results of the average values of all simulation runs. The user is not allowed to change the values presented on this table, since this is an output screen

The tabulated results present the average values of the five replications, where the simulation duration is 360 days (in other words, twelve months). The user is able to view the results by choosing the regarding replication number (from first to fifth) and the desired type of graphics among the followings:

- Revenues, Costs and Profits of the whole supply chain versus time,
- Total Costs of all members versus time,
    - Inventory holding costs of all members versus time,
    - Backordering costs of all members versus time,

- Purchasing costs of all members versus time,

- Revenues of all members versus time,
- Profits of all members versus time,
- Inventory levels of all members versus time for each run.

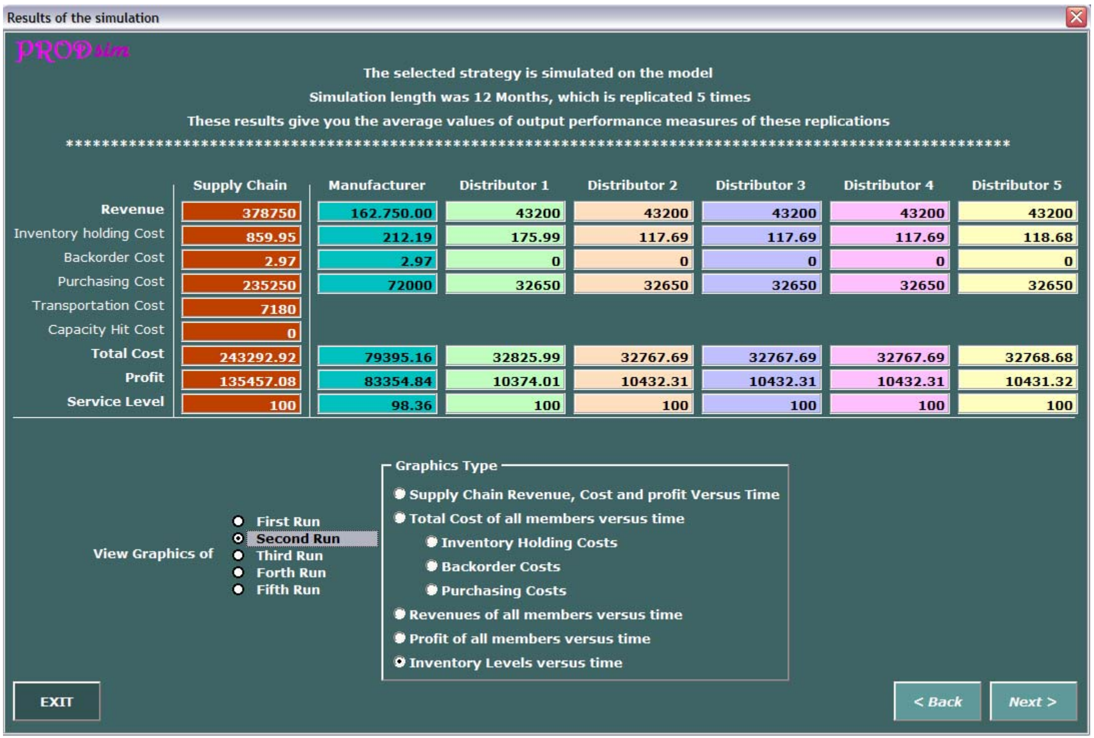


Figure 20. Screen that shows the results of the simulation run

For example, in order to show the graph of the inventory levels in the second run of the simulation model, the user should select the replication number as the "Second Run" and the related graphics type of "Inventory Levels versus time" and should press the "Next" button to view the graphical representation in Figure 21.

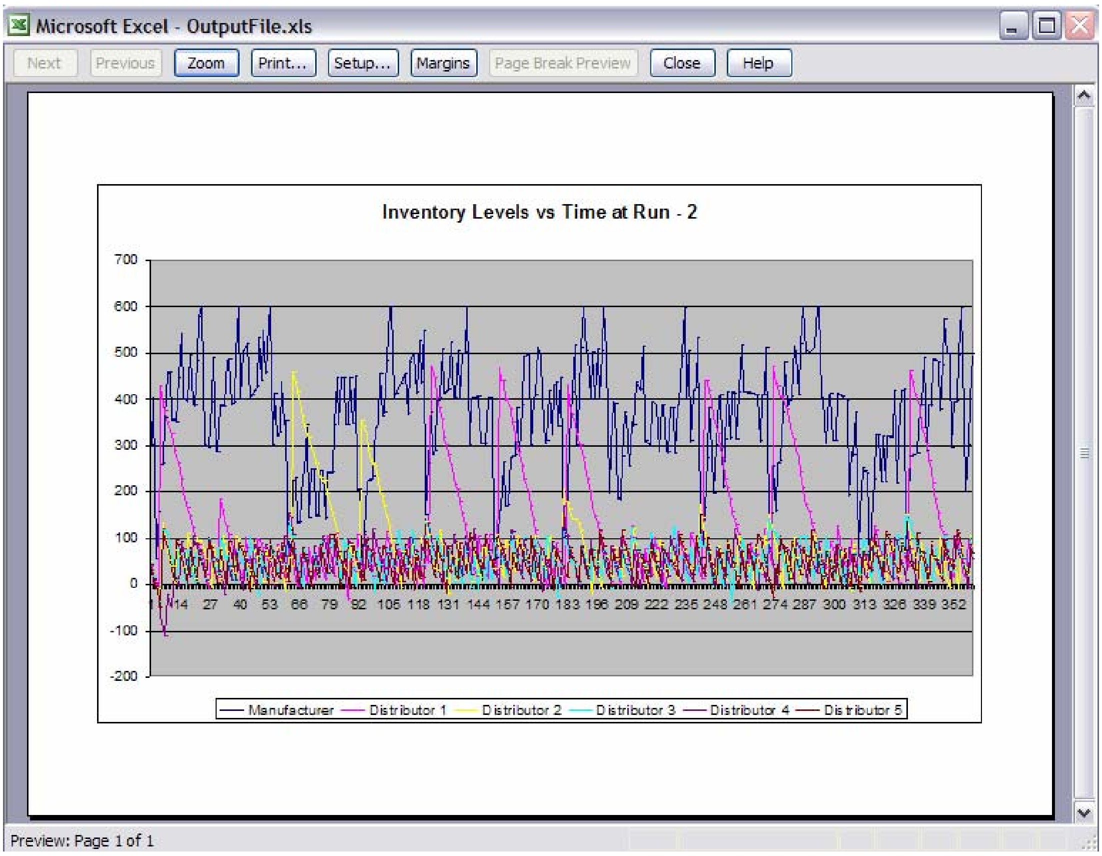


Figure 21. Graphical representation of inventory levels versus time

After the window is displayed for the selected graphics, the user can return to the results screen by closing this window using the “Close” button or may return to the previous screen by pressing the “Back” button, so as to select another model and run it with the same input values to make comparison within the models. Moreover, the user may leave the ProdSIM environment by clicking on the “Exit” button.

Similarly, in order to show the graph of the total inventory holding costs in the third run of the simulation model, the user should select the replication number as the “Third Run” and the related graphics type of “Inventory Holding Costs versus time” and should press the “Next” button to view the graphical representation in Figure 22.

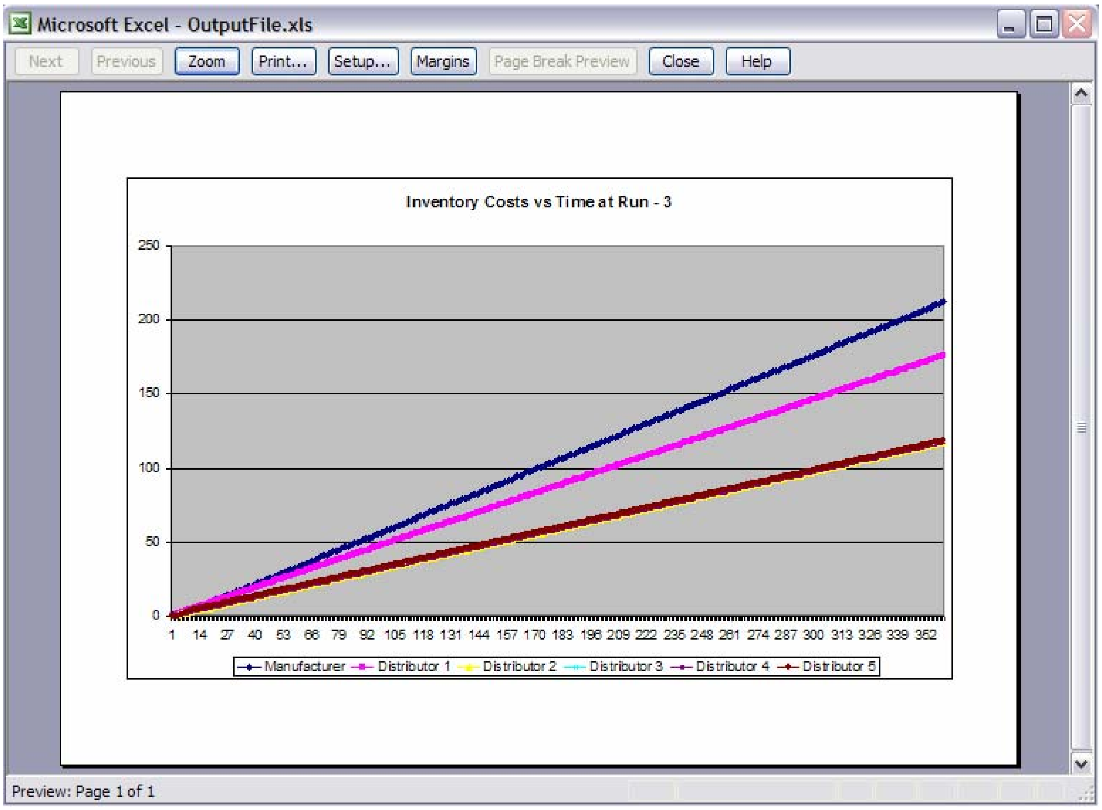


Figure 22. Graphical representation of inventory holding costs versus time

CHAPTER 8

CONCLUSION

Supply chain systems are complex systems involving several parties with different goals. Simulation is suggested as a very suitable technique to learn the complex dynamics structure of the supply chain, conduct sensitivity analysis on the decision variables and estimated input parameters. However simulation models should be incorporated into a DSS environment to be used in the real time and generate valid results for the decision makers.

In this study a simulation-based decision support system (DSS) for one of the biggest commodity manufacturers in Turkey is developed. The DSS provides the supply chain managers the ability to make better decisions. The managers interact with the easy to use GUI, called "PRODsim," and change the input values to see the influence on the output performance measures of the supply chain under different policies.

Three simulation models are developed by using the software package ARENA (version: 10.00.00). The first model represents the current system of the studied supply chain, which applies a "Monthly Quota" strategy for deciding on the volume discount option. In this model, the manufacturer is not able to see the demand of its distributor. The second model stands for the system, where an information system is integrated to the current system that makes the POS data of the distributors available to the manufacturer. This model enables the manufacturer to see the daily end-demand of the supply chain and make better predictions for future demand. Finally, in the third model, another strategy for deciding on the volume discount option is recommended. In this third model, the manufacturer decides on the volume discounts by checking the fulfillment of distributors' quotas at each order, instead of at the end of each month.

All three simulation models are run with different values of basic input parameters selected in the experimental design, which are the demand variability and the discount rate, to show the advantages of integrating an information system to share the end-demand information between the downstream and upstream members of supply chain; and the benefits obtained by applying a "Rolling Horizon" policy instead of the "Monthly Quota" policy.

The results of the experimental design show that the system, where an information system is integrated into the supply chain to allow an information flow upwards in the chain, yields a better performance than the base scenario at all levels of demand variability and at all levels of discount rates. "Rolling Horizon" strategy decreases the "Hockey-Stick Phenomenon" by preventing the amplification of the order amounts at the end of the evaluation periods. Checking the quotas of distributors on a "Rolling Horizon" basis yields a better performance for the overall supply chain and the individual members in the supply chain in terms of decreasing the costs and increasing the profits as well as increasing the service levels.

Two main conclusions are drawn; it is found that for the overall supply chain performance (i) the “Monthly Quota” strategy with information sharing outperforms the “Monthly Quota” strategy without information sharing and (ii) the “Rolling Horizon” strategy outperforms the “Monthly Quota” strategy by the increased supply chain profit and immediate order satisfaction rate under the existence of information sharing.

From the perspective of the supply chain parties the benefits obtained by the “Monthly Quota with IS” and “Rolling Horizon with IS” policies might slightly differ. For the manufacturer, profits slightly increase in “Monthly Quota with IS” whereas the service levels are improved significantly when compared to the current system. From the distributors’ point of view, profits increase significantly in “Monthly Quota with IS” whereas the service levels are improved slightly. On the other hand, “Rolling Horizon with IS” provides a significant improvement in manufacturer profit and service level. From the distributors’ point of view, profits slightly increase in “Rolling Horizon with IS” whereas the service levels are improved slightly as compared to the “Monthly Quota with IS” model. However, overall, the “Rolling Horizon with IS” policy brings a significant improvement both to the manufacturer and the distributors compared to the base scenario.

As future work, the Decision Support System environment may be enhanced to operate faster with more features. As an example, one study could be to run all three different simulation models simultaneously by parallel computing and report the comparison results. Moreover, the comparison criteria may be taken from the supply chain managers through another screen developed in the DSS environment.

Another enhancement option for the DSS environment may be providing flexibility for the number of the distributors and their demand distributions. This feature would provide a dynamic supply chain configuration and thus provide a sophisticated DSS environment for the decision makers in the supply chain.

Finally, the output analysis of the simulation models may be enhanced by incorporating other performance measures that might be useful.

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APPENDIX

A. RESULTS OF EXPERIMENTS

Case results for C1

Case 1 (Monthly Quota without IS, 0% Demand Variability, 10% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	372225,00	156225,00	43200,00	43200,00	43200,00	43200,00	43200,00	x 1000 YTL
Inventory Holding Cost	1802,76	454,80	154,94	123,85	553,20	401,34	114,64	x 1000 YTL
Backorder Cost	889,40	80,19	78,62	258,74	25,29	53,08	393,48	x 1000 YTL
Purchasing Cost	236510,75	67785,75	32875,00	32800,00	35175,00	35175,00	32700,00	x 1000 YTL
Transportation Cost	6730,00	6730,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	37000,00	37000,00	x	x	x	x	x	x 1000 YTL
Total Cost	282932,91	112050,74	33108,56	33182,59	35753,49	35629,42	33208,12	x 1000 YTL
Profit	89292,09	44174,26	10091,44	10017,41	7446,51	7570,58	9991,88	x 1000 YTL
Service Levels	94,63	64,59	97,63	91,50	99,44	98,02	86,57	%

Case 2 (Monthly Quota with IS, 0% Demand Variability, 10% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	374925,00	158925,00	43200,00	43200,00	43200,00	43200,00	43200,00	x 1000 YTL
Inventory Holding Cost	1208,41	445,67	158,80	151,92	151,17	151,17	149,69	x 1000 YTL
Backorder Cost	395,70	10,52	297,92	17,47	17,47	17,52	34,80	x 1000 YTL
Purchasing Cost	233725,00	71300,00	32475,00	32500,00	32500,00	32500,00	32450,00	x 1000 YTL
Transportation Cost	7070,00	7070,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	3000,00	3000,00	x	x	x	x	x	x 1000 YTL
Total Cost	245399,11	81826,18	32931,71	32669,39	32668,65	32668,70	32634,49	x 1000 YTL
Profit	129525,89	77098,82	10268,29	10530,61	10531,35	10531,30	10565,51	x 1000 YTL
Service Levels	97,79	93,27	90,36	99,72	99,72	99,72	99,44	%

Case 3 (Rolling Horizon with IS, 0% Demand Variability, 10% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	378750,00	162750,00	43200,00	43200,00	43200,00	43200,00	43200,00	x 1000 YTL
Inventory Holding Cost	859,95	212,19	175,99	117,69	117,69	117,69	118,68	x 1000 YTL
Backorder Cost	2,97	2,97	0,00	0,00	0,00	0,00	0,00	x 1000 YTL
Purchasing Cost	235250,00	72000,00	32650,00	32650,00	32650,00	32650,00	32650,00	x 1000 YTL
Transportation Cost	7180,00	7180,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	0,00	0,00	x	x	x	x	x	x 1000 YTL
Total Cost	243292,92	79395,16	32825,99	32767,69	32767,69	32767,69	32768,68	x 1000 YTL
Profit	135457,08	83354,84	10374,01	10432,31	10432,31	10432,31	10431,32	x 1000 YTL
Service Levels	100,00	98,36	100,00	100,00	100,00	100,00	100,00	%

Case 4 (Monthly Quota without IS, 25% Demand Variability, 10% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	378451,87	162356,67	43336,00	42926,00	43397,20	43284,00	43152,00	x 1000 YTL
Inventory Holding Cost	1551,04	384,14	314,92	295,02	193,84	179,90	183,22	x 1000 YTL
Backorder Cost	1525,26	62,55	221,63	212,34	309,09	326,77	392,88	x 1000 YTL
Purchasing Cost	238189,65	70766,32	34105,00	33790,00	33406,67	33101,67	33020,00	x 1000 YTL
Transportation Cost	7030,00	7030,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	15733,33	15733,33	x	x	x	x	x	x 1000 YTL
Total Cost	264029,29	93976,34	34641,56	34297,36	33909,59	33608,34	33596,10	x 1000 YTL
Profit	114422,58	68380,33	8694,44	8628,64	9487,61	9675,66	9555,90	x 1000 YTL
Service Levels	91,84	70,81	93,70	93,86	91,28	90,61	89,73	%

Case 5 (Monthly Quota with IS, 25% Demand Variability, 10% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	371340,20	155245,00	43336,00	42926,00	43397,20	43284,00	43152,00	x 1000 YTL
Inventory Holding Cost	1405,88	445,83	372,27	159,51	151,56	139,96	136,75	x 1000 YTL
Backorder Cost	965,20	34,80	118,51	156,08	223,30	203,17	229,35	x 1000 YTL
Purchasing Cost	233894,87	68816,53	34398,33	32573,33	32875,00	32678,33	32553,33	x 1000 YTL
Transportation Cost	6841,33	6841,33	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	9266,67	9266,67	x	x	x	x	x	x 1000 YTL
Total Cost	252373,95	85405,16	34889,11	32888,92	33249,86	33021,46	32919,43	x 1000 YTL
Profit	118966,25	69839,84	8446,89	10037,08	10147,34	10262,54	10232,57	x 1000 YTL
Service Levels	94,64	80,49	95,95	95,24	93,92	94,35	93,76	%

Case 6 (Rolling Horizon with IS, 25% Demand Variability, 10% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	378341,87	162246,67	43336,00	42926,00	43397,20	43284,00	43152,00	x 1000 YTL
Inventory Holding Cost	1086,06	353,66	148,02	147,95	144,66	145,31	146,46	x 1000 YTL
Backorder Cost	174,59	3,46	34,82	30,81	35,75	33,46	36,29	x 1000 YTL
Purchasing Cost	235452,93	72272,93	32740,00	32416,67	32713,33	32653,33	32656,67	x 1000 YTL
Transportation Cost	7194,67	7194,67	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	133,33	133,33	x	x	x	x	x	x 1000 YTL
Total Cost	244041,58	79958,05	32922,83	32595,42	32893,75	32832,11	32839,41	x 1000 YTL
Profit	134300,29	82288,61	10413,17	10330,58	10503,45	10451,89	10312,59	x 1000 YTL
Service Levels	94,64	98,02	94,60	94,78	94,76	94,64	94,43	%

Case 7 (Monthly Quota without IS, 50% Demand Variability, 10% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	378956,93	162823,33	43513,60	43483,20	43154,80	42778,40	43203,60	x 1000 YTL
Inventory Holding Cost	1489,81	361,28	378,33	233,69	183,39	191,33	141,78	x 1000 YTL
Backorder Cost	1749,98	59,87	148,84	316,56	392,93	365,89	465,90	x 1000 YTL
Purchasing Cost	238016,82	71060,15	34656,67	33791,67	33013,33	32726,67	32768,33	x 1000 YTL
Transportation Cost	7069,33	7069,33	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	14466,67	14466,67	x	x	x	x	x	x 1000 YTL
Total Cost	262792,61	93017,30	35183,84	34341,92	33589,65	33283,89	33376,02	x 1000 YTL
Profit	116164,32	69806,03	8329,76	9141,28	9565,15	9494,51	9827,58	x 1000 YTL
Service Levels	90,39	71,89	95,46	90,21	89,20	89,59	87,47	%

Case 8 (Monthly Quota with IS, 50% Demand Variability, 10% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	370390,27	154256,67	43513,60	43483,20	43154,80	42778,40	43203,60	x 1000 YTL
Inventory Holding Cost	1385,10	439,86	331,95	183,52	151,75	142,43	135,59	x 1000 YTL
Backorder Cost	1281,69	40,10	155,83	243,75	277,29	240,02	324,70	x 1000 YTL
Purchasing Cost	233597,47	68174,13	34258,33	33375,00	32866,67	32336,67	32586,67	x 1000 YTL
Transportation Cost	6788,00	6788,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	9933,33	9933,33	x	x	x	x	x	x 1000 YTL
Total Cost	252985,59	85375,43	34746,12	33802,27	33295,71	32719,11	33046,95	x 1000 YTL
Profit	117404,68	68881,24	8767,48	9680,93	9859,09	10059,29	10156,65	x 1000 YTL
Service Levels	92,43	78,29	94,77	92,34	92,00	92,57	90,47	%

Case 9 (Rolling Horizon with IS, 50% Demand Variability, 10% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	378303,60	162170,00	43513,60	43483,20	43154,80	42778,40	43203,60	x 1000 YTL
Inventory Holding Cost	1077,39	341,89	148,56	145,42	146,52	147,70	147,28	x 1000 YTL
Backorder Cost	252,38	5,69	49,98	51,22	49,35	47,19	48,95	x 1000 YTL
Purchasing Cost	235345,20	72108,53	32900,00	32820,00	32540,00	32330,00	32646,67	x 1000 YTL
Transportation Cost	7187,33	7187,33	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	600,00	600,00	x	x	x	x	x	x 1000 YTL
Total Cost	244462,30	80243,45	33098,53	33016,65	32735,88	32524,89	32842,90	x 1000 YTL
Profit	133841,30	81926,55	10415,07	10466,55	10418,92	10253,51	10360,70	x 1000 YTL
Service Levels	92,22	96,68	92,42	91,98	92,40	92,22	92,09	%

Case 10 (Monthly Quota without IS, 75% Demand Variability, 10% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	389397,87	166246,67	44614,40	44951,60	44828,00	44260,80	44496,40	x 1000 YTL
Inventory Holding Cost	1311,29	399,08	340,76	189,30	164,60	126,73	90,83	x 1000 YTL
Backorder Cost	4534,98	91,66	628,46	799,35	896,90	966,08	1152,53	x 1000 YTL
Purchasing Cost	243370,14	72723,47	35083,33	34426,67	34336,67	33563,33	33236,67	x 1000 YTL
Transportation Cost	7229,33	7229,33	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	16066,67	16066,67	x	x	x	x	x	x 1000 YTL
Total Cost	272512,40	96510,20	36052,55	35415,32	35398,16	34656,14	34480,02	x 1000 YTL
Profit	116885,47	69736,46	8561,85	9536,28	9429,84	9604,66	10016,38	x 1000 YTL
Service Levels	70,52	63,83	77,17	71,54	70,43	69,32	64,16	%

Case 11 (Monthly Quota with IS, 75% Demand Variability, 10% Discount Rate)

	Output Performance Measures							
	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	382376,20	159225,00	44614,40	44951,60	44828,00	44260,80	44496,40	x 1000 YTL
Inventory Holding Cost	1358,77	429,58	329,67	168,36	152,54	140,77	137,85	x 1000 YTL
Backorder Cost	1944,07	43,98	258,38	400,60	388,32	420,35	432,44	x 1000 YTL
Purchasing Cost	241258,60	70200,27	35321,67	34350,00	34303,33	33545,00	33538,33	x 1000 YTL
Transportation Cost	6996,67	6996,67	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	9600,00	9600,00	x	x	x	x	x	x 1000 YTL
Total Cost	261158,10	87270,49	35909,72	34918,96	34844,19	34106,12	34108,62	x 1000 YTL
Profit	121218,10	71954,51	8704,68	10032,64	9983,81	10154,68	10387,78	x 1000 YTL
Service Levels	88,71	77,19	91,13	88,38	88,42	87,71	87,92	%

Case 12 (Rolling Horizon with IS, 75% Demand Variability, 10% Discount Rate)

	Output Performance Measures							
	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	390121,20	166970,00	44614,40	44951,60	44828,00	44260,80	44496,40	x 1000 YTL
Inventory Holding Cost	1041,75	318,67	146,51	143,22	143,73	144,86	144,76	x 1000 YTL
Backorder Cost	407,27	8,34	83,34	81,93	81,62	77,59	74,44	x 1000 YTL
Purchasing Cost	242982,13	74112,13	33753,33	33946,67	33940,00	33536,67	33693,33	x 1000 YTL
Transportation Cost	7394,00	7394,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	866,67	866,67	x	x	x	x	x	x 1000 YTL
Total Cost	252691,82	82699,81	33983,18	34171,82	34165,35	33759,12	33912,54	x 1000 YTL
Profit	137429,38	84270,19	10631,22	10779,78	10662,65	10501,68	10583,86	x 1000 YTL
Service Levels	88,22	95,14	88,00	88,12	87,66	88,49	88,84	%

Case results for C2

Case 13 (Monthly Quota without IS, 0% Demand Variability, 20% Discount Rate)

	Output Performance Measures							
	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	361700,00	145700,00	43200,00	43200,00	43200,00	43200,00	43200,00	x 1000 YTL
Inventory Holding Cost	1749,87	454,80	139,10	110,09	547,37	396,61	101,90	x 1000 YTL
Backorder Cost	1125,47	69,05	104,36	344,98	27,13	55,31	524,63	x 1000 YTL
Purchasing Cost	225985,75	67785,75	30000,00	29600,00	34600,00	34600,00	29400,00	x 1000 YTL
Transportation Cost	6730,00	6730,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	37000,00	37000,00	x	x	x	x	x	x 1000 YTL
Total Cost	272591,08	112039,60	30243,46	30055,07	35174,50	35051,92	30026,54	x 1000 YTL
Profit	89108,92	33660,40	12956,54	13144,93	8025,50	8148,08	13173,46	x 1000 YTL
Service Levels	94,63	64,59	97,63	91,50	99,44	98,02	86,57	%

Case 14 (Monthly Quota with IS, 0% Demand Variability, 20% Discount Rate)

	Output Performance Measures							
	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	357600,00	141600,00	43200,00	43200,00	43200,00	43200,00	43200,00	x 1000 YTL
Inventory Holding Cost	1125,04	445,67	142,53	135,04	134,38	134,38	133,06	x 1000 YTL
Backorder Cost	520,92	8,42	396,15	23,30	23,30	23,36	46,40	x 1000 YTL
Purchasing Cost	216400,00	71300,00	29200,00	29000,00	29000,00	29000,00	28900,00	x 1000 YTL
Transportation Cost	7070,00	7070,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	3000,00	3000,00	x	x	x	x	x	x 1000 YTL
Total Cost	228115,96	81824,08	29738,68	29158,33	29157,67	29157,74	29079,45	x 1000 YTL
Profit	129484,04	59775,92	13461,32	14041,67	14042,33	14042,26	14120,55	x 1000 YTL
Service Levels	97,79	93,27	90,36	99,72	99,72	99,72	99,44	%

Case 15 (Rolling Horizon with IS, 0% Demand Variability, 20% Discount Rate)

	Output Performance Measures							
	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	362000,00	146000,00	43200,00	43200,00	43200,00	43200,00	43200,00	x 1000 YTL
Inventory Holding Cost	853,31	212,19	173,78	116,59	116,59	116,59	117,58	x 1000 YTL
Backorder Cost	2,97	2,97	0,00	0,00	0,00	0,00	0,00	x 1000 YTL
Purchasing Cost	218500,00	72000,00	29300,00	29300,00	29300,00	29300,00	29300,00	x 1000 YTL
Transportation Cost	7180,00	7180,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	0,00	0,00	x	x	x	x	x	x 1000 YTL
Total Cost	226536,28	79395,16	29473,78	29416,59	29416,59	29416,59	29417,58	x 1000 YTL
Profit	135463,72	66604,84	13726,22	13783,41	13783,41	13783,41	13782,42	x 1000 YTL
Service Levels	100,00	98,36	100,00	100,00	100,00	100,00	100,00	%

Case 16 (Monthly Quota without IS, 25% Demand Variability, 20% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	365925,20	149830,00	43336,00	42926,00	43397,20	43284,00	43152,00	x 1000 YTL
Inventory Holding Cost	1484,50	384,14	302,12	282,10	180,01	166,92	169,21	x 1000 YTL
Backorder Cost	1930,29	53,11	280,56	261,90	398,38	426,68	509,65	x 1000 YTL
Purchasing Cost	225662,99	70766,32	32126,67	31846,67	30730,00	30136,67	30056,67	x 1000 YTL
Transportation Cost	7030,00	7030,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	15733,33	15733,33	x	x	x	x	x	x 1000 YTL
Total Cost	251841,11	93966,90	32709,35	32390,67	31308,39	30730,27	30735,53	x 1000 YTL
Profit	114084,09	55863,10	10626,65	10535,33	12088,81	12553,73	12416,47	x 1000 YTL
Service Levels	91,84	70,81	93,70	93,86	91,28	90,61	89,73	%

Case 17 (Monthly Quota with IS, 25% Demand Variability, 20% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	356485,20	140390,00	43336,00	42926,00	43397,20	43284,00	43152,00	x 1000 YTL
Inventory Holding Cost	1325,78	445,83	355,48	142,53	135,62	124,76	121,56	x 1000 YTL
Backorder Cost	1248,90	28,34	141,41	207,17	296,37	269,82	305,80	x 1000 YTL
Purchasing Cost	219039,87	68816,53	32730,00	29396,67	29650,00	29340,00	29106,67	x 1000 YTL
Transportation Cost	6841,33	6841,33	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	9266,67	9266,67	x	x	x	x	x	x 1000 YTL
Total Cost	237722,55	85398,71	33226,89	29746,36	30081,99	29734,58	29534,02	x 1000 YTL
Profit	118762,65	54991,29	10109,11	13179,64	13315,21	13549,42	13617,98	x 1000 YTL
Service Levels	94,64	80,49	95,95	95,24	93,92	94,35	93,76	%

Case 18 (Rolling Horizon with IS, 25% Demand Variability, 20% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	361621,87	145526,67	43336,00	42926,00	43397,20	43284,00	43152,00	x 1000 YTL
Inventory Holding Cost	1077,94	353,66	146,36	146,33	143,06	143,70	144,84	x 1000 YTL
Backorder Cost	231,33	3,32	46,39	41,06	47,63	44,60	48,33	x 1000 YTL
Purchasing Cost	218732,93	72272,93	29380,00	29100,00	29360,00	29306,67	29313,33	x 1000 YTL
Transportation Cost	7194,67	7194,67	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	133,33	133,33	x	x	x	x	x	x 1000 YTL
Total Cost	227370,20	79957,92	29572,74	29287,39	29550,69	29494,96	29506,50	x 1000 YTL
Profit	134251,66	65568,75	13763,26	13638,61	13846,51	13789,04	13645,50	x 1000 YTL
Service Levels	94,64	98,02	94,60	94,78	94,76	94,64	94,43	%

Case 19 (Monthly Quota without IS, 50% Demand Variability, 20% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	366180,27	150046,67	43513,60	43483,20	43154,80	42778,40	43203,60	x 1000 YTL
Inventory Holding Cost	1424,64	361,28	365,34	221,72	170,23	177,18	128,90	x 1000 YTL
Backorder Cost	2223,49	50,95	181,25	401,10	507,38	477,01	605,81	x 1000 YTL
Purchasing Cost	225240,15	71060,15	33113,33	31433,33	30160,00	29836,67	29636,67	x 1000 YTL
Transportation Cost	7069,33	7069,33	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	14466,67	14466,67	x	x	x	x	x	x 1000 YTL
Total Cost	250424,28	93008,38	33659,92	32056,15	30837,60	30490,85	30371,37	x 1000 YTL
Profit	115755,98	57038,28	9853,68	11427,05	12317,20	12287,55	12832,23	x 1000 YTL
Service Levels	90,39	71,89	95,46	90,21	89,20	89,59	87,47	%

Case 20 (Monthly Quota with IS, 50% Demand Variability, 20% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	373141,20	149990,00	44614,40	44951,60	44828,00	44260,80	44496,40	x 1000 YTL
Inventory Holding Cost	1034,54	318,67	145,02	141,78	142,29	143,43	143,34	x 1000 YTL
Backorder Cost	537,14	7,32	110,84	108,90	108,45	102,83	98,79	x 1000 YTL
Purchasing Cost	226002,13	74112,13	30340,00	30526,67	30513,33	30206,67	30303,33	x 1000 YTL
Transportation Cost	7394,00	7394,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	866,67	866,67	x	x	x	x	x	x 1000 YTL
Total Cost	235834,48	82698,78	30595,87	30777,35	30764,08	30452,93	30545,46	x 1000 YTL
Profit	137306,72	67291,22	14018,53	14174,25	14063,92	13807,87	13950,94	x 1000 YTL
Service Levels	88,22	95,14	88,00	88,12	87,66	88,49	88,84	%

Case 21 (Rolling Horizon with IS, 50% Demand Variability, 20% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	361690,27	145556,67	43513,60	43483,20	43154,80	42778,40	43203,60	x 1000 YTL
Inventory Holding Cost	1069,85	341,89	147,02	143,93	145,01	146,23	145,76	x 1000 YTL
Backorder Cost	333,48	5,28	66,53	68,18	65,68	62,77	65,05	x 1000 YTL
Purchasing Cost	218731,87	72108,53	29533,33	29473,33	29230,00	29043,33	29343,33	x 1000 YTL
Transportation Cost	7187,33	7187,33	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	600,00	600,00	x	x	x	x	x	x 1000 YTL
Total Cost	227922,53	80243,04	29746,88	29685,44	29440,69	29252,34	29554,15	x 1000 YTL
Profit	133767,73	65313,63	13766,72	13797,76	13714,11	13526,06	13649,45	x 1000 YTL
Service Levels	92,22	96,68	92,42	91,98	92,40	92,22	92,09	%

Case 22 (Monthly Quota without IS, 75% Demand Variability, 20% Discount Rate)

	Output Performance Measures							
	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	375877,87	152726,67	44614,40	44951,60	44828,00	44260,80	44496,40	x 1000 YTL
Inventory Holding Cost	1264,63	399,08	331,02	180,18	155,37	117,32	81,67	x 1000 YTL
Backorder Cost	5888,90	76,97	805,43	1040,99	1171,50	1265,66	1528,35	x 1000 YTL
Purchasing Cost	229850,14	72723,47	33316,67	31870,00	31606,67	30510,00	29823,33	x 1000 YTL
Transportation Cost	7229,33	7229,33	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	16066,67	16066,67	x	x	x	x	x	x 1000 YTL
Total Cost	260299,66	96495,52	34453,12	33091,16	32933,53	31892,98	31433,35	x 1000 YTL
Profit	115578,20	56231,15	10161,28	11860,44	11894,47	12367,82	13063,05	x 1000 YTL
Service Levels	70,52	63,83	77,17	71,54	70,43	69,32	64,16	%

Case 23 (Monthly Quota with IS, 75% Demand Variability, 20% Discount Rate)

	Output Performance Measures							
	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	367884,53	144733,33	44614,40	44951,60	44828,00	44260,80	44496,40	x 1000 YTL
Inventory Holding Cost	1283,66	429,58	313,93	153,10	137,77	126,28	123,00	x 1000 YTL
Backorder Cost	2510,75	36,58	314,67	522,91	508,73	554,42	573,45	x 1000 YTL
Purchasing Cost	226766,93	70200,27	33476,67	31366,67	31306,67	30323,33	30093,33	x 1000 YTL
Transportation Cost	6996,67	6996,67	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	9600,00	9600,00	x	x	x	x	x	x 1000 YTL
Total Cost	247158,01	87263,09	34105,26	32042,67	31953,17	31004,03	30789,79	x 1000 YTL
Profit	120726,52	57470,24	10509,14	12908,93	12874,83	13256,77	13706,61	x 1000 YTL
Service Levels	88,71	77,19	91,13	88,38	88,42	87,71	87,92	%

Case 24 (Rolling Horizon with IS, 75% Demand Variability, 20% Discount Rate)

	Output Performance Measures							
	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	373141,20	149990,00	44614,40	44951,60	44828,00	44260,80	44496,40	x 1000 YTL
Inventory Holding Cost	1034,54	318,67	145,02	141,78	142,29	143,43	143,34	x 1000 YTL
Backorder Cost	537,14	7,32	110,84	108,90	108,45	102,83	98,79	x 1000 YTL
Purchasing Cost	226002,13	74112,13	30340,00	30526,67	30513,33	30206,67	30303,33	x 1000 YTL
Transportation Cost	7394,00	7394,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	866,67	866,67	x	x	x	x	x	x 1000 YTL
Total Cost	235834,48	82698,78	30595,87	30777,35	30764,08	30452,93	30545,46	x 1000 YTL
Profit	137306,72	67291,22	14018,53	14174,25	14063,92	13807,87	13950,94	x 1000 YTL
Service Levels	88,22	95,14	88,00	88,12	87,66	88,49	88,84	%

Case results for C3

Case 25 (Monthly Quota without IS, 0% Demand Variability, 30% Discount Rate)

	Output Performance Measures							
	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	351175,00	135175,00	43200,00	43200,00	43200,00	43200,00	43200,00	x 1000 YTL
Inventory Holding Cost	1696,98	454,80	123,26	96,33	541,55	391,88	89,17	x 1000 YTL
Backorder Cost	1361,53	57,92	130,10	431,23	28,96	57,54	655,79	x 1000 YTL
Purchasing Cost	215460,75	67785,75	27125,00	26400,00	34025,00	34025,00	26100,00	x 1000 YTL
Transportation Cost	6730,00	6730,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	37000,00	37000,00	x	x	x	x	x	x 1000 YTL
Total Cost	262249,26	112028,46	27378,36	26927,55	34595,50	34474,42	26844,96	x 1000 YTL
Profit	88925,74	23146,54	15821,64	16272,45	8604,50	8725,58	16355,04	x 1000 YTL
Service Levels	94,63	64,59	97,63	91,50	99,44	98,02	86,57	%

Case 26 (Monthly Quota with IS, 0% Demand Variability, 30% Discount Rate)

	Output Performance Measures							
	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	340275,00	124275,00	43200,00	43200,00	43200,00	43200,00	43200,00	x 1000 YTL
Inventory Holding Cost	1041,66	445,67	126,26	118,16	117,58	117,58	116,42	x 1000 YTL
Backorder Cost	646,14	6,31	494,38	29,12	29,12	29,20	58,00	x 1000 YTL
Purchasing Cost	199075,00	71300,00	25925,00	25500,00	25500,00	25500,00	25350,00	x 1000 YTL
Transportation Cost	7070,00	7070,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	3000,00	3000,00	x	x	x	x	x	x 1000 YTL
Total Cost	210832,80	81821,98	26545,64	25647,28	25646,70	25646,78	25524,42	x 1000 YTL
Profit	129442,20	42453,02	16654,36	17552,72	17553,30	17553,22	17675,58	x 1000 YTL
Service Levels	97,79	93,27	90,36	99,72	99,72	99,72	99,44	%

Case 27 (Rolling Horizon with IS, 0% Demand Variability, 30% Discount Rate)

	Output Performance Measures							
	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	345250,00	129250,00	43200,00	43200,00	43200,00	43200,00	43200,00	x 1000 YTL
Inventory Holding Cost	846,68	212,19	171,57	115,48	115,48	115,48	116,47	x 1000 YTL
Backorder Cost	2,97	2,97	0,00	0,00	0,00	0,00	0,00	x 1000 YTL
Purchasing Cost	201750,00	72000,00	25950,00	25950,00	25950,00	25950,00	25950,00	x 1000 YTL
Transportation Cost	7180,00	7180,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	0,00	0,00	x	x	x	x	x	x 1000 YTL
Total Cost	209779,65	79395,16	26121,57	26065,48	26065,48	26065,48	26066,47	x 1000 YTL
Profit	135470,35	49854,84	17078,43	17134,52	17134,52	17134,52	17133,53	x 1000 YTL
Service Levels	100,00	98,36	100,00	100,00	100,00	100,00	100,00	%

Case 28 (Monthly Quota without IS, 25% Demand Variability, 30% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	353398,53	137303,33	43336,00	42926,00	43397,20	43284,00	43152,00	x 1000 YTL
Inventory Holding Cost	1417,96	384,14	289,31	269,19	166,19	153,94	155,20	x 1000 YTL
Backorder Cost	2335,31	43,68	339,49	311,46	487,67	526,59	626,42	x 1000 YTL
Purchasing Cost	213136,32	70766,32	30148,33	29903,33	28053,33	27171,67	27093,33	x 1000 YTL
Transportation Cost	7030,00	7030,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	15733,33	15733,33	x	x	x	x	x	x 1000 YTL
Total Cost	239652,93	93957,47	30777,14	30483,98	28707,19	27852,19	27874,96	x 1000 YTL
Profit	113745,60	43345,87	12558,86	12442,02	14690,01	15431,81	15277,04	x 1000 YTL
Service Levels	91,84	70,81	93,70	93,86	91,28	90,61	89,73	%

Case 29 (Monthly Quota with IS, 25% Demand Variability, 30% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	341630,20	125535,00	43336,00	42926,00	43397,20	43284,00	43152,00	x 1000 YTL
Inventory Holding Cost	1245,68	445,83	338,70	125,55	119,69	109,55	106,36	x 1000 YTL
Backorder Cost	1532,61	21,89	164,30	258,25	369,44	336,48	382,25	x 1000 YTL
Purchasing Cost	204184,87	68816,53	31061,67	26220,00	26425,00	26001,67	25660,00	x 1000 YTL
Transportation Cost	6841,33	6841,33	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	9266,67	9266,67	x	x	x	x	x	x 1000 YTL
Total Cost	223071,15	85392,25	31564,67	26603,80	26914,12	26447,70	26148,61	x 1000 YTL
Profit	118559,05	40142,75	11771,33	16322,20	16483,08	16836,30	17003,39	x 1000 YTL
Service Levels	94,64	80,49	95,95	95,24	93,92	94,35	93,76	%

Case 30 (Rolling Horizon with IS, 25% Demand Variability, 30% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	344901,87	128806,67	43336,00	42926,00	43397,20	43284,00	43152,00	x 1000 YTL
Inventory Holding Cost	1069,83	353,66	144,70	144,71	141,45	142,09	143,23	x 1000 YTL
Backorder Cost	288,07	3,18	57,96	51,31	59,51	55,73	60,37	x 1000 YTL
Purchasing Cost	202012,93	72272,93	26020,00	25783,33	26006,67	25960,00	25970,00	x 1000 YTL
Transportation Cost	7194,67	7194,67	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	133,33	133,33	x	x	x	x	x	x 1000 YTL
Total Cost	210698,83	79957,78	26222,65	25979,35	26207,63	26157,82	26173,60	x 1000 YTL
Profit	134203,04	48848,89	17113,35	16946,65	17189,57	17126,18	16978,40	x 1000 YTL
Service Levels	94,64	98,02	94,60	94,78	94,76	94,64	94,43	%

Case 31 (Monthly Quota without IS, 50% Demand Variability, 30% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	353403,60	137270,00	43513,60	43483,20	43154,80	42778,40	43203,60	x 1000 YTL
Inventory Holding Cost	1359,47	361,28	352,34	209,75	157,06	163,02	116,01	x 1000 YTL
Backorder Cost	2697,00	42,03	213,66	485,64	621,83	588,13	745,71	x 1000 YTL
Purchasing Cost	212463,49	71060,15	31570,00	29075,00	27306,67	26946,67	26505,00	x 1000 YTL
Transportation Cost	7069,33	7069,33	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	14466,67	14466,67	x	x	x	x	x	x 1000 YTL
Total Cost	238055,95	92999,47	32136,00	29770,39	28085,56	27697,81	27366,73	x 1000 YTL
Profit	115347,65	44270,53	11377,60	13712,81	15069,24	15080,59	15836,87	x 1000 YTL
Service Levels	90,39	71,89	95,46	90,21	89,20	89,59	87,47	%

Case 32 (Monthly Quota with IS, 50% Demand Variability, 30% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	341570,27	125436,67	43513,60	43483,20	43154,80	42778,40	43203,60	x 1000 YTL
Inventory Holding Cost	1225,59	439,86	295,82	151,13	120,26	111,99	106,52	x 1000 YTL
Backorder Cost	2024,79	26,69	226,55	386,63	453,58	396,23	535,12	x 1000 YTL
Purchasing Cost	204777,47	68174,13	30308,33	27825,00	26666,67	25910,00	25893,33	x 1000 YTL
Transportation Cost	6788,00	6788,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	9933,33	9933,33	x	x	x	x	x	x 1000 YTL
Total Cost	224749,18	85362,01	30830,70	28362,76	27240,51	26418,22	26534,98	x 1000 YTL
Profit	116821,09	40074,65	12682,90	15120,44	15914,29	16360,18	16668,62	x 1000 YTL
Service Levels	92,43	78,29	94,77	92,34	92,00	92,57	90,47	%

Case 33 (Rolling Horizon with IS, 50% Demand Variability, 30% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	345076,93	128943,33	43513,60	43483,20	43154,80	42778,40	43203,60	x 1000 YTL
Inventory Holding Cost	1062,32	341,89	145,48	142,43	143,50	144,77	144,25	x 1000 YTL
Backorder Cost	414,58	4,87	83,08	85,13	82,01	78,35	81,15	x 1000 YTL
Purchasing Cost	202118,53	72108,53	26166,67	26126,67	25920,00	25756,67	26040,00	x 1000 YTL
Transportation Cost	7187,33	7187,33	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	600,00	600,00	x	x	x	x	x	x 1000 YTL
Total Cost	211382,76	80242,63	26395,22	26354,23	26145,51	25979,78	26265,39	x 1000 YTL
Profit	133694,17	48700,71	17118,38	17128,97	17009,29	16798,62	16938,21	x 1000 YTL
Service Levels	92,22	96,68	92,42	91,98	92,40	92,22	92,09	%

Case 34 (Monthly Quota without IS, 75% Demand Variability, 30% Discount Rate)

Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	362357,87	139206,67	44614,40	44951,60	44828,00	44260,80	44496,40	x 1000 YTL
Inventory Holding Cost	1217,97	399,08	321,29	171,06	146,13	107,91	72,52	x 1000 YTL
Backorder Cost	7242,82	62,29	982,41	1282,62	1446,09	1565,24	1904,17	x 1000 YTL
Purchasing Cost	216330,14	72723,47	31550,00	29313,33	28876,67	27456,67	26410,00	x 1000 YTL
Transportation Cost	7229,33	7229,33	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	16066,67	16066,67	x	x	x	x	x	x 1000 YTL
Total Cost	248086,93	96480,83	32853,69	30767,01	30468,89	29129,82	28386,68	x 1000 YTL
Profit	114270,94	42725,83	11760,71	14184,59	14359,11	15130,98	16109,72	x 1000 YTL
Service Levels	70,52	63,83	77,17	71,54	70,43	69,32	64,16	%

Case 35 (Monthly Quota with IS, 75% Demand Variability, 30% Discount Rate)

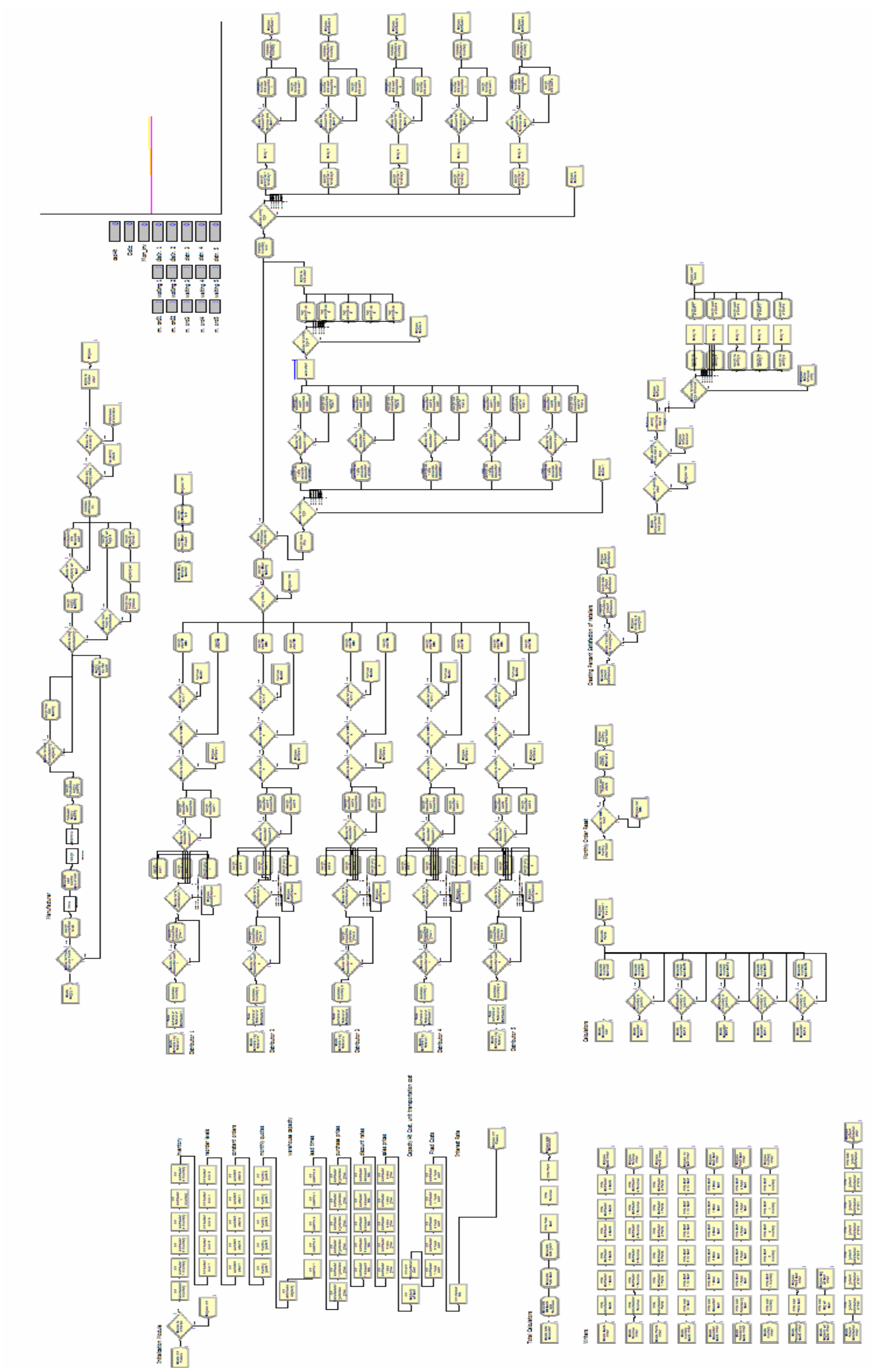
Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	353392,87	130241,67	44614,40	44951,60	44828,00	44260,80	44496,40	x 1000 YTL
Inventory Holding Cost	1208,56	429,58	298,19	137,84	123,01	111,78	108,16	x 1000 YTL
Backorder Cost	3077,43	29,17	370,95	645,21	629,15	688,49	714,46	x 1000 YTL
Purchasing Cost	212275,27	70200,27	31631,67	28383,33	28310,00	27101,67	26648,33	x 1000 YTL
Transportation Cost	6996,67	6996,67	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	9600,00	9600,00	x	x	x	x	x	x 1000 YTL
Total Cost	233157,92	87255,69	32300,81	29166,39	29062,15	27901,94	27470,95	x 1000 YTL
Profit	120234,94	42985,98	12313,59	15785,21	15765,85	16358,86	17025,45	x 1000 YTL
Service Levels	88,71	77,19	91,13	88,38	88,42	87,71	87,92	%

Case 36 (Rolling Horizon with IS, 75% Demand Variability, 30% Discount Rate)

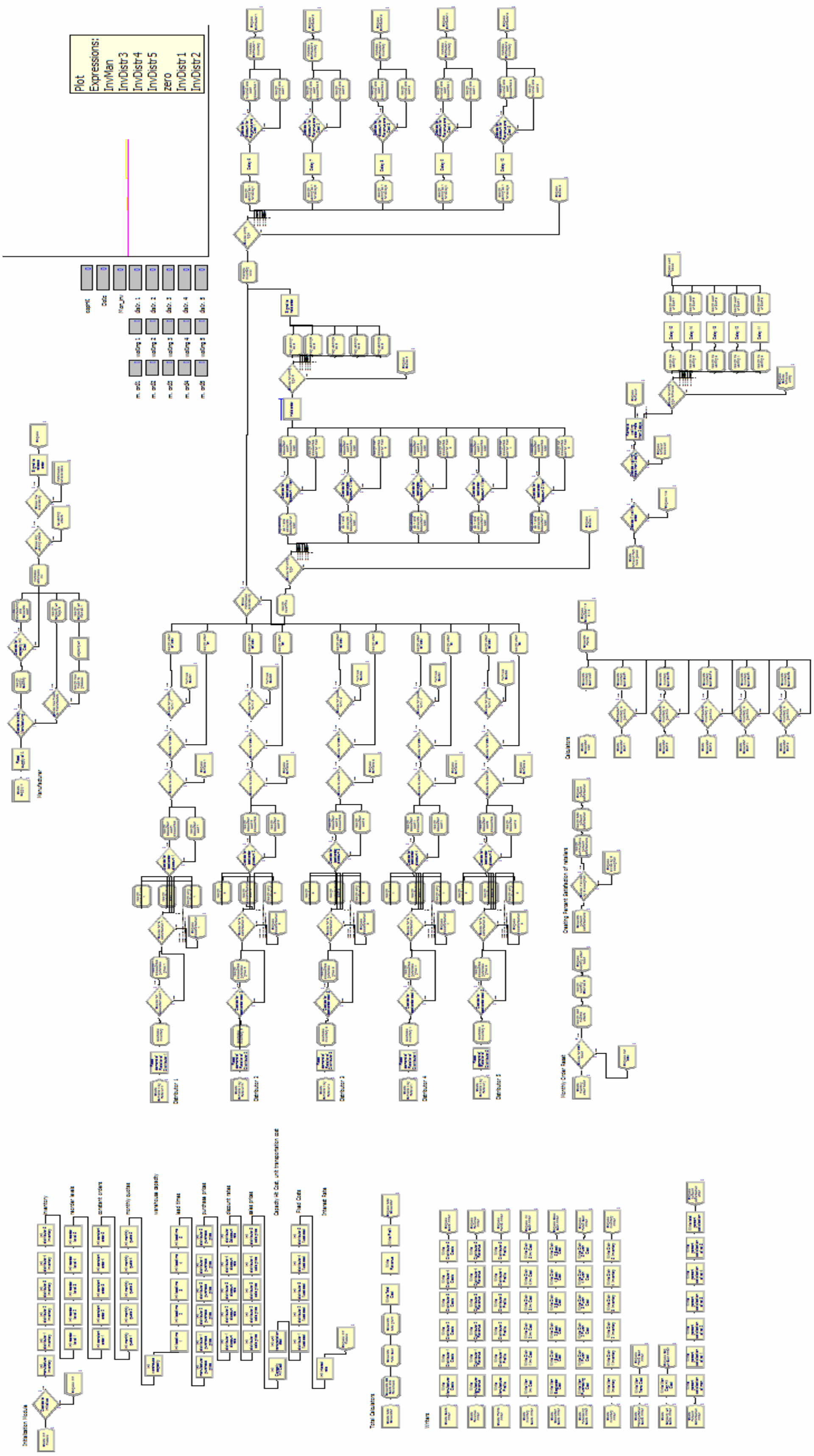
Output Performance Measures	Supply Chain	Manufacturer	1. Distributor	2. Distributor	3. Distributor	4. Distributor	5. Distributor	
Revenue	356161,20	133010,00	44614,40	44951,60	44828,00	44260,80	44496,40	x 1000 YTL
Inventory Holding Cost	1027,33	318,67	143,54	140,35	140,86	142,00	141,91	x 1000 YTL
Backorder Cost	667,01	6,29	138,35	135,87	135,29	128,07	123,15	x 1000 YTL
Purchasing Cost	209022,13	74112,13	26926,67	27106,67	27086,67	26876,67	26913,33	x 1000 YTL
Transportation Cost	7394,00	7394,00	x	x	x	x	x	x 1000 YTL
Capacity Hit Cost	866,67	866,67	x	x	x	x	x	x 1000 YTL
Total Cost	218977,14	82697,76	27208,55	27382,89	27362,81	27146,74	27178,39	x 1000 YTL
Profit	137184,06	50312,24	17405,85	17568,71	17465,19	17114,06	17318,01	x 1000 YTL
Service Levels	88,22	95,14	88,00	88,12	87,66	88,49	88,84	%

B. SIMULATION MODELS

Monthly Quota without Information Sharing



Monthly Quota with Information Sharing



Rolling Horizon with Information Sharing