FMCG SUPPLY CHAIN NETWORK DESIGN

UNDER UNCERTAINTY

FARABİ AKSU

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ABSTRACT

FMCG SUPPLY CHAIN NETWORK DESIGN
UNDER UNCERTAINTY

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Today’s market conditions force companies expand their operations worldwide. Therefore commercial organizations are exploring new markets where they can attract new consumers, and trying to increase their market share in the regions they are currently operating in. This tough competition is more severe in the Fast Moving Consumer Goods (FMCG) industry where there is a high level of uncertainty, mainly due to rapid change of customer needs and wants. For such companies, managing the supply chain with lower costs becomes even more critical for keeping their existing customers and expanding their operations via new markets. Under these market conditions optimizing the supply chain then becomes a severe challenge.

This study focuses on network optimization for a Fortune 500 company that operates globally in FMCG sector. Our main concern is re-designing the supply network of the company involving multiple items and entities such as suppliers, distribution and production centers, under demand and lead time uncertainties. We analyze an alternate business model that utilizes supply hubs. In terms of analysis, we consider two different perspectives; decreasing the total supply chain cost and utilizing the advantages of risk pooling effect via supply hubs.

Keywords: Supply Chain Network Design, Uncertainty in Supply Chain, Inventory Management via Simulation, Supply Hubs, Supply Chain Simulation.

ÖZET

DEĞİŞKEN HIZLI TÜKETİM PAZARINA AİT TEDARİK ZİNCİRİ AĞ TASARIMI

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Günümüz Pazar dinamikleri şirketleri sürekli büyüme ve pazarda geniş alanlara yayılmaya zorlamaktadır. Global pazarın da yönlendirmesi ile şirketler yeni pazarlar keşfetme ve yeni müşteriler kazanma yolu ile daha çok müşteriye ulaşıp içerisinde bulundukları pazar paylarını ve karlılık düzeylerini arttırma çabasındadır. Özellikle hızlı tüketim sektöründe faaliyet gösteren firmalar bu hedeflere ulaşmak ve için rakipleri ile daha sıkı bir rekabet içerisindedir. Bu büyük rekabetin nedeni de bu sektörde müşterilerin talep ve isteklerinin fazlaca değişkenlik göstermesidir. Hızlı tüketim sektöründe faaliyet gösteren bu firmalar için tedarik zincirini en az maliyet ve yüksek müşteri memnuniyeti ile yönetmek daha da zordur. Zira bu firmalar, pazar ve müşteri talep değişikliklerini göz önünde bulundurup, mevcut müşterilerini koruyarak yeni müşterilere ulaşmak için yeni pazar arayışına girmek durumundadırlar. Bu nedenlerden dolayı, hızlı tüketim sektöründe tedarik zinciri yönetimi çok daha zordur denilebilir

Bu çalışma, küresel büyüklük olarak Fortune 500 listesinde bulunan bir hızlı tüketim şirketinin tedarik zinciri yapısının iyileştirilmesini konu almıştır. Çalışmadaki ana amaç, şirketin dünyanın farklı yerlerinde konumlanmış birden fazla tedarikçisi ve üretim tesislerinin de içerisinde bulunduğu, talebin ve tedarik zamanının değişken olduğu yapı altında; tedarik zincirini yapılandırarak bu yapının iyileştirilebilme alternatiflerini görmektir. Bu alternatif, tedarik zinciri yapısında üretim tesisleri ile tedarikçiler arasına dağıtım merkezlerini konumlandırma stratejisi üzerine dayanmaktadır. Tedarik zinciri iyileştirme anlamında iki farklı temel amaç bulunmaktadır. Bu amaçlar: toplam tedarik zinciri maliyetini düşürmek ve müşteri memnuniyet oranını arttırmaktır.

Anahtar Kelimeler: Tedarik Zinciri Ağ Tasarımı, Tedarik Zincirindeki Belirsizlikler, Simülasyon ile Envanter Yönetimi, Tedarik Merkezleri, Tedarik Zinciri Simülasyonu.

To My Family

I would like to dedicate this thesis to my family; especially my mother Müyesser and father Nuri Aksu. They are supporting me at every step of my life. Besides, I would like to express special thanks to my brother Teoman, my girlfriend İlçim and my all friends.

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CHAPTER I

INTRODUCTION

In today’s dynamic marketplace companies are struggling to increase their market shares by expanding their operations worldwide. As the operation, decision points and information flow expand, supply chain management (SCM) becomes more critical issue since managing the coordination between supply chain entities becomes more severe task. A supply chain with well-established coordination and collaboration creates a win-win case where all supply chain partners will benefit. Christopher (1992) emphasizes that the real competition takes part through supply chains instead of companies. In order to survive in this though competition, companies are targeting to sustain coordination, cooperation and collaboration through their supply chain partners that can directly affect the whole supply chain structure and process.

Nowadays, multinational companies are aiming to enhance their worldwide supply chain operations in order to increase their market shares and gain competitive advantage through their competitors. Most of them are searching for alternatives in order to construct the most efficient supply chain structure or process that will enable them to have the least total operational cost and high effectiveness with desired customer satisfaction level. While searching for alternative supply chain structures or improving the current supply chain operations, one of the most severe issue is coping with the uncertainties in the market and within their supply chain.

The uncertain environment complicates companies' short and long term plans and strategies. In order to cope with the uncertainties, global firms have been looking for a systematic way to predict future scenarios effectively. Uncertainty i.e. dynamic market, forces companies to review and update their current supply chain operations with both short and long term plans. In this respect, supply chain design under uncertainty begins to take attractions in the literature for a few decades.

Uncertainty in supply chain design generally refers demand, supply capacity and lead time fluctuations (Lawrence, Mark and Chung, 2005). These uncertainties are more common in fast moving consumer good (FMCG) market which is directly driven by consumer needs and wants. In this sector, consumers play a vital role through supply chain partners. In such a market, it is very complicated to forecast consumer demand which will shape the whole supply chain process. For this reason, FMCG companies are trying to have a high level of customer satisfaction which is directly related with quality and cost parameters. In this respect, these firms are focusing on providing high quality and service level with the possible least cost with an aim of satisfying their existing customers and attracting new ones. Thus, minimization of total supply chain operating cost is one of the most common strategies of FMCG companies which operate in a market where high level of competition takes part. This minimization requires a well-designed and operated supply chain and logistics structure with advanced information flow.

The aim of this thesis is providing a decision support tool that provides various supply chain design and process alternatives with whole cost illustrations for the optimization of the worldwide inventory management and logistics processes of a Fortune 500 multinational FMCG company. The main concern is to evaluate the total cost of the current logistics processes and to compare it with the proposed alternative structures by considering demand, supply, lead time and in-house uncertainty. While analyzing the dynamic logistics processes, inbound logistics flows and warehousing will be the core subjects of this study. In this respect, number and location of hubs to be opened will be able to be determined and evaluated under uncertain environment with an objective of total logistics cost minimization.

While minimizing total logistics cost; transportation, inventory holding, custom clearance, agency and opportunity costs are considered. These costs are compared under two different scenarios by considering hubs and no hubs in the supply chain models. In addition to minimization of total logistics cost, elimination of stock out risk and enhancement of the operational efficiency of current inbound logistics processes which can directly affect the customer satisfaction level will be the supporting themes of the study.

This thesis is composed of six main components. The first chapter focuses on on providing general information about the main topic of the thesis. In the first chapter, a typical industry problem is defined by considering studied company's current supply chain process. After defining the current supply chain situation of the mentioned company, objectives and motivation of the thesis are illustrated. Finally, the methodology used in thesis is explained. In the second chapter, literature review related with the main theme of this study has been presented. The third chapter details the studied company's current business processes, cost components are detailed with the illustration of simulation model's setting. In the fourth chapter, two alternate supply chain designs and its cost components and main settings are discussed. In the fifth section, the outputs of the current supply chain structure and alternate supply chain designs are demonstrated. Finally, the last section provides conclusion about the thesis and the further future research issues.

1.1. Problem Definition

During this study, one of the fortune 500 multinational companies which operate in geographically dispersed regions is analyzed. When the current business process of the company is analyzed it is observed that current supply chain structure is typical as many globally operating multinational companies.

The company we are considering has so many production centers located in various geographical areas and for administrative purposes they are clustered in “regions” based on their proximity to each other. Manufacturers in the same region also share a common supplier base, which induces the supply network of the region. We will not focus on the whole entities of this company; instead we will analyze a single region composed of six manufacturing sites that takes part in different countries.

Basically, these manufacturing plants in the region supply their raw material directly from their suppliers and after value-added activities are performed, final products are sold in their specific domestic and export markets. In this traditional procurement model, purchasing orders are placed for the suppliers and after a specific lead time they are received by the manufacturer warehouses. Later, finished goods are sent to the distributors which can be regarded as customers. This system is composed of two echelon supply chain network with a link between suppliers and manufacturers and another link between manufacturers and customers. See Figure 1.1

Through this specific region, we will focus on the inbound part of the supply chain where there are suppliers and manufacturers. In this part of the supply chain, production centers place their orders for the suppliers and after a specific lead time and required logistics processes they acquire the ownership of the materials. These materials are stored in manufacturer’s own warehouse until they are used in production. Thus, the inbound part of supply chain which is in the scope of this thesis is a single echelon system.

Regarding inventory management, suppliers and regional manufacturers are holding their inventory and safety stocks in their own facilities. For this reason, when a shipment is released by supplier to manufacturer an invoice receipt takes part. After a certain lead time, manufacturer takes the ownership of the materials by storing them in its warehouse. Figure 1.1 represents the summary of the current (traditional) business procurement model.

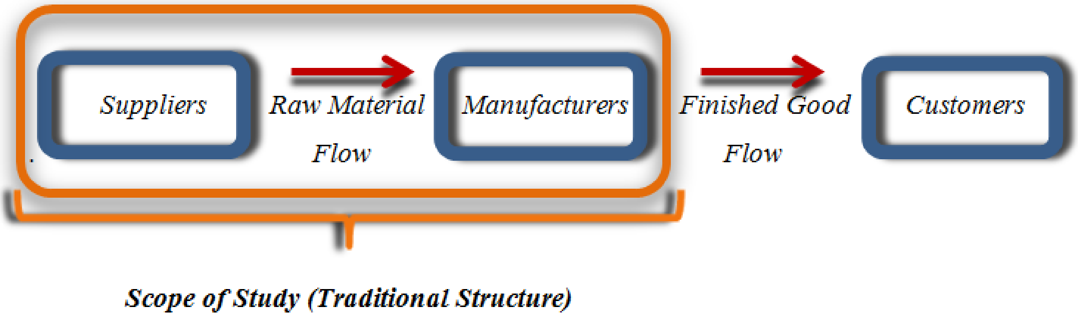
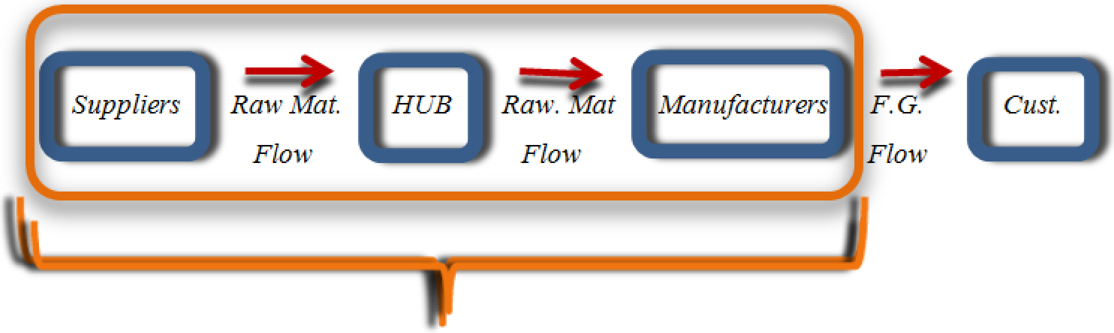


Figure 1.1: Scope of Study (Traditional Structure)

Above current (traditional) procurement structure results in separate inventory levels for each manufacturer which are supplied by various suppliers that are located in different regions of the world. This generates high level of cash flow for the manufacturer. In order to have a saving in terms of cash flow and have a better inventory management regarding to the prevention of possible stock outs, an alternative business model can be applied for this multinational company. Namely this approach can be applied by considering hub(s) which is located as a buffer between suppliers and manufacturers as it is indicated in the below scheme.



Scope of Study (Proposed Structure)

Figure 1.2: Scope of Study (Traditional Structure)

1.2. Objective of the Thesis

The main objective of this thesis is to analyze different supply chain designs and operations for multinational companies operating in a quite dynamic environment in terms of both strategic and operational manner, and to propose the best alternative that maximizes the customer satisfaction level and minimizes total supply chain cost which mainly includes transportation, custom clearance, inventory holding and back order costs.

We also aim to analyze the uncertain parameters of the business environment which the company mentioned in this thesis operates. These uncertain parameters cause make the company a strategic or tactical decision harder. Thus, simulating this uncertainty and overviewing alternative supply chain structures and operations and then comparing their performances in terms of total supply chain cost and customer satisfaction level are the main contribution of this thesis.

The research basically looks for the answers of the following questions;

- What advantages can the introduction of supply hubs into supply chain network design of a multinational company under uncertainty provide?
- How do the cost components and total logistics cost of alternate supply chain design under uncertainty differ from traditional structure without hub?
- How does uncertainty (introduction of stochastic parameters) affect the supply chain performance?
- How does the supply chain behave under various inventory policies, demand levels and demand uncertainty levels?

1.3. Motivation of the Thesis

The topic of this thesis is based on Göçer (2010). She defines the current supply network of the company with an analytical model and develops an alternative business model that considers consolidation of shipments through supply hubs. The setting involves multiple suppliers providing multiple products to multiple manufacturers. The products under consideration are high-volume, high unit priced items with deterministic demand and constant lead times. She follows an approach that implements analytical methods i.e. and mathematical model by identifying the cost structures and outlining the optimal conditions for all parties involved in both models.

In this thesis, most of the parameters, structural concept and ideas are similar to Göçer (2010). However, there are several differences between this thesis and Göçer (2010). The first difference is that we use simulation in order to consider the stochastic environment (e.g. demand, lead time) of the supply chain. Göçer's study was considering the demand and lead time as deterministic and according to that model's output it was suggesting to open a main warehouse in Turkey region (Göçer, 2010). However this study considers stochastic data which is than considering deterministic data. Instead of using an analytical method, simulation technique i.e. Arena Software is used in order to simulate daily business operations in an effective way. Finally, another new insight is indicating the risk pooling advantage that will be encountered by holding the whole inventory in the same location which will lead the company to sum the whole separated risks into a single point. It is so clear that the risk of facing with stock-out with the proposed design (using a supply hub) will be less than the current supply chain structure of the company. Thus the main motivation of this study is to reflect the real life scenario as much as possible with a new designed simulation model by considering demand and lead time variability and illustrating the risk pooling advantage of the proposed alternate model.

1.4. Methodology

In this thesis, we develop a simulation model of the studied supply chain network by considering uncertainty. In order to incorporate uncertainty there are many methods to be used such as stochastic programming, simulation and other analytical methods. Our theme, supply chain design, requires strategic, tactical and operational level decisions to be taken into consideration. Even though our research questions seem to be regarding strategic and tactical decisions, we think that operational decisions may also play an important role while taking a strategic level decision. For this reason, the scope of our study consists of strategic, tactical and operational level considerations. After analyzing several alternative methods available in the literature we decide to use simulation since it can handle uncertainty and also enable us to include the operational insights in addition to strategic ones.

Simulation is one of the fundamental approaches that can be used to model problems in the presence of uncertainty. Thus, during the modeling stage of the project, Arena

Software is used in order to reflect real life circumstances such as demand and lead time fluctuations.

Using simulation, we could also consider strategic, dynamic and operational variables that take part in the current business environment. In order to reflect real life structure smoothly, this technique is one of the best alternatives where manipulating within the supply chain environment is quite practical by altering a few modules. Moreover, since the main concept of this thesis is to observe the advantages and disadvantages of hub(s) including between suppliers and manufacturer as an alternative design, observing economies of scale and risk pooling effects that will result from consolidating inventory sites is vital. Thus, we thought that simulation is a compatible tool that can handle these considerations, enables us trying alternate tactical and operational structures and comparing them with each other.

The main objective in this simulation model is analyzing different supply chain designs both strategically and operationally, and finding out the best alternative one minimizing the total supply chain cost mainly including transportation, custom clearance, ordering, inventory holding and backorder costs and increasing the customer fill rate. The underlying idea of the model used in this study is allowing unmet or partially met demand in the system with back order cost. In this respect, simulation methodology can also handle these concerns easily.

In the first part of the modelling, Arena 14.50 student version is used in order to construct the environment. However, later on student version could not cope with the complexity of the model in terms of the number of entities and modules being used. For this reason, the whole structure is re-built by using Arena 14.00 simulation software’s academic version which is only permitted to use for academic purposes. For this reason, university laboratory is used to build and run the model.

This model simulates the real life material and information flow which starts with the demand of customer and ends with the supply of materials via suppliers. By simulating various alternatives such as demand, standard deviation and re order level different scenarios created. Alternate factors and levels are represented in Table 1.1. All these scenarios include different strategic i.e. opening a supply hub(s) and operational decisions i.e. determination of re order level. Comparing different scenarios with their outputs enable us to find out the best structure and its cost and customer satisfaction details.

Table 1.1: Factors and Levels used in Simulation Model as an Alternative Setting

Factors	Levels		
Demand	Low	Medium	High
Standard Deviation	10%	30%	60%
Re-order Level	Company Policy	90% Service Level	98% Service Level
Supply Chain Structure	No Hub	1 Hub	2 Hubs

Totally there are 81 different scenarios are considered in the modeling stage. The main components of these scenarios are number of hubs, standard deviation of demand (10%, 30% and 60%) demand amount (low, medium and high demand) and customer service strategy (company policy, 90% and 98% service levels).

In terms of number of hubs mainly there are 3 alternative supply chain designs which are without hub (company's current environment), 1 hub (distribution center) included system and two hubs included scenarios.

The other scenario component is the demand's standard deviation which is listed with three alternatives such as 10%, 30% and 60% standard deviation of demand. It is obvious that in today's dynamic environment reviewing small, medium and high fluctuated demand is a valid scenario for most companies. Thus, we prefer to include three different standard deviation of demand as listed above.

The third scenario group is again related with demand uncertainty. However, this time we consider the changes in demand itself. Although the demand in simulation model has already had an uncertainty with a normal distribution and standard deviation we thought that mean demand itself may fluctuated downward or upward with the changing behavior of todays' consumers. For this reason we define three different scenarios where the demand is moderate, low and high. We assume 50% percent ratio to calculate low and high demand scenarios. For example if a weekly normal demand of a material is 100 units, then in low demand case we take the demand as 50 units whereas in high demand scenario it is considered as 150 units.

The last scenario group is about re-order level. Out of periodic inventory management policies, we follow (*s*,*S*) ordering policy through our study where *s* represent re-order point (ROP) and *S* represents order up to level. In this policy, when inventory level is equal to *s* or decrease under *s*, the ordering amount becomes *S* – inventory position. ROP is represented by ''*s*'' in our model we define 3 different *s* levels. The first alternative is the company's current average demand policy which refers holding inventory as: demand during lead time plus 1 month average demand. This policy says that *s* should be equal to demand that will occur during lead time of a specific material plus the demand that will incur within one month. It is obvious that company's current policy is quite satisfactory in terms of customer satisfaction level while it is dissatisfactory in terms of cash flow and inventory holding cost.

As an alternative to company's current re-order level policy we prefer to use type 2 service level which simply refers the ratio of demand satisfied from stock equal to specific ratio. This service level is generally referred as fill rate. Through this respect, we defined two additional alternative service levels which are 90% and 98% fill rates. These rates represent satisfying the demand's 90% or 98% from the on hand inventory.

In order to use these ratios, we have calculated new re-order levels loaded them into the simulation model.

Through the modeling stage, all inputs are updated at every alternate model and after models are run, reports are received for each single alternative. All these alternative scenarios widen the scope of the study in terms of coping with uncertainty and comparison of them between each other. Moreover, running the same model with various alternative standard deviations and demand rates enable us measuring different scenarios' outputs. Since demand uncertainty is one of the biggest concerns in most industries we thought that assessing various cases make companies to review the best or worst case and take necessary precautions in advance.

In summary, using a simulation engine that will enables to repeat scenarios that are related with various operational alternatives until a good enough solution is obtained is the main component of this thesis. It enables us to reflect real life cases as much as possible. Accordingly, the implementation of this study will be more attractive for the company in terms of optimizing its current supply chain design and processes which can directly contribute total supply chain cost and demand fill rate.

After deciding on the method that will be followed through the study we have started to analyze and simulate company's current business structure. During this stage, we also clarified the decisions that will be taken, responsibilities through supply chain partners and parameters that are currently being used in the real life over the supply chain.

During th modelling stage, first off all real life supply chain system is simulated by using various blocks in Arena. After simulating the current structure which is composed of suppliers and manufacturers in the scope of this study hubs are located into the simulation which will create an alternate supply chain design proposed as an alternative in this thesis. This stage is the main and first part of modelling which can be regarded as construction of alternate (two echelon supply chain) system instead of current single echelon system.

Through simulating the real life system, all operations that take part in the current structure of the company are started to be added into the model with Arena software. These operations start with the creation of a manufacturer's demand for a stock keeping unit (SKU) and ends with the supply of material. There are many different operations between these two such as checking inventory levels, order realizing, order preparation, consolidation on orders, shipment releases, calculation of related logistics costs such as transportation, ordering, custom clearance, inventory holding and back order costs that will illustrate the whole system cost after running the model.

After validation and verification processes, as a final stage 81 different models which has a specific scenario has been run and all of their reports are kept by using statistics module in simulation. In terms of these statistics; average inventory levels, transportation cost, total ordering cost, total custom cost, inventory holding cost, total demand and fill rate variables are kept trough the model for each single material and manufacturer. By exporting the reports of Arena to Excel sheets several analyses in terms of total logistics cost and demand fill rate are performed for each alternative.

1.5. Validation and Verification

In terms of validation of the simulation model we are directed by company advisors. During the modelling stage both industry and company advisors assist and help us in every step to validate the structure of the model. Furthermore, Göçer (2010) study which was proved before as a valid and verified structure also help us to determine all operations that will be added into the simulation model as in the real life. Comparing the result of that deterministic model and our simulation model with the same data set, we are able to control our simulation model's validity.

In terms of the verification of the model, whole Arena Simon Code has been checked with academic advisors in order to find out if any mistake is made. Then, a simple data set is created to check whether the model works properly. After this test, real data as inputs are loaded into the simulation model. In terms of these inputs, all data used in simulation model is directly supplied by industry advisors. Thus, using a real data assist to replicate real life case as much as possible. By using these data all supply chain costs are identified and added into the simulation model. After inputs are loaded into the model, example model runs are taken and by using different track and trace modules in Arena the model is tested with the real data. Many different graphics and outputs are observed in order to trace inventory flow in the structure. Thereafter, all model inputs and outputs are controlled by industry and academic advisors and feasibility of the model is approved by both sides.

During this verification process we also prepare a data set which represents the real life data taken from the studied company. By using this data set we have run the simulation model and gather the related results. Later, we compare the result of simulation model and real results (based on a past data) on company side. After this comparison, we are sure about the validity and verification of the simulation model.

CHAPTER II

LITERATURE REVIEW

Through this chapter literature review discussions about supply chain management, supply chain design, supply chain simulation and inventory management via simulation concepts are discussed. While these discussions the similarities and difference between the existing literature and our thesis have been analyzed and mentioned.

2.1 Supply Chain Management (SCM)

Supply chain (SC) has evolved from the era when issues related to materials flow were introduced (Forrester, 1961), that later on become part of supply chain management. As Cooper (1997) refers the term supply chain management (SCM) has risen to prominence over the past twenty years in the literature. For instance, in 1995 13.5% of the concurrent session titles contained the words ‘supply chain’ at Annual Conference of the Council of Logistics Management. In the same conference, two years later, the number of sessions that includes the term ‘supply chain’ increase to 22.4%. As Ross (1998) mentioned SCM has become such a "hot topic" that it is so severe to confront with an inventory management, manufacturing, logistics, distribution or marketing article without referring to SCM-related topics. Especially since 1990, SC spread very rapidly by showing an exponential growth through academic papers and industry (Burgess et al., 2006).

SCM refers the management of the material and information flow between supply chain entities which are suppliers, manufacturers, distributors, wholesalers, retailers and customers (Thomas and Griffin, 1996). In the past, these entities are only focusing on succeeding their own goal without any cooperation and collaboration through other supply chain partners. They were making decisions without collaborating with their supply chain partners. This management philosophy creates different management point of views in a single supply chain. Somehow these decisions may be contradicting to each other which will result a poor managed supply chain that affects each entity directly.

For example, regarding inventory management, supply chain entities may be dispersed into different geographical regions which hold their own inventory in their own facilities. Deciding on inventory and safety stock levels without knowing your partners' inventory level and policy may create significantly high inventory levels. In this case, the total supply chain cost increases immeasurably too with the risk of holding inventory such as opportunity cost, obsolescence, deterioration. On the contrary, deciding inventory or safety stock level without any collaboration may also create too low inventory levels which may result a stock out risk that will also result a customer loss. In both cases all organizations in the same chain can be affected negatively. As a result of such negative effects, companies are altering their decision making processes toward coordinated and integrated manner instead of independent ones.

Through global business community Supply Chain Management has being received a great deal of attention due to its significant cost impact in the market. refers that in the United States annual expenditures on non-military logistics are estimated at $670 million; over 11% of the Gross National Product. With logistics costs of 30% of cost of goods sold, not uncommon for U.S. manufacturing firms. For this reason, potential savings in supply chain management cannot be ignored. In order to have SCM cost reduction benefits a well design supply chain with integration, cooperation and collaboration is quite necessary.

In addition to significant cost saving opportunities, SCM also plays a vital role in terms of customer satisfaction level. Nowadays, consumers are mainly focusing on three concepts which are quality, cost and on time delivery. Except from quality of a product or a service itself, costs of goods sold and on time delivery are directly related with supply chain management and logistics. For this reason, global conditions are forcing companies to decrease their cost and increase customer satisfaction level in order to survive in the market. Since it is too severe to increase customer satisfaction and decrease cost of goods or service sold at the same time, a well-designed and operated SC which will decrease overall supply chain cost and increase customer satisfaction level plays a vital role.

Through coordination, collaboration and integration in SCM, gaining a competitive advantage by decreasing total logistics cost and increase customer service level in the market can be possible for organizations. For this reason, nowadays, traditional supply chain structure where a few organizations operates independently and have conflicting objectives is being replaced by interdependent organizations that operates optimally with integrated objectives through re-designing their supply chain networks, that enables an effective and efficient supply chain management (Altıparmak et al., 2009).

Towards these aspects, in terms of SCM the literature is closely interrelated with coordination, collaboration and integration concepts which were underlined before in order to clarify the importance of them to have a well-designed and operating supply chain. With an aim of increasing the performance and effectiveness in terms of aligning and coordinating the individual business activities and processes, significant effort has been put by both academicians and industry practitioners Göçer (2010).

Through the literature there are different definitions of coordination in SC by various academicians. Arun et al. (2008) listed them in a chorological order with a review study. For example, it can be defined as a particular degree of relationship among chain members as a means to share risks and rewards that result in higher business performance than would be achieved by the firms individually (Lambert et al., 1999). In terms of responsibility concept the ability of logistics function to integrate interrelated supply chain activities across different lines of organizational authority and responsibility can be understood (Ballou et al., 2000). Another perspective of coordination by Narus and Anderson (1996) is the cooperation among independent but related firms to share resources and capabilities to meet their customers' most extraordinary needs.

Coordination through supply chain entities can be supplied in a vertical or horizontal way. The vertical coordination refers the link between suppliers and manufacturer while horizontal coordination means the communication between two different suppliers that operate for the same manufacturer. Mentioned link between these entities might be an operational such as inventory management, logistics, manufacturing or another. In this respect, important concepts are information sharing and joint decision making process which can assist the minimization of total operating cost.

Coordination requires an integration through the supply chain with a target of increasing the value added activities by redefining and connecting business processes and creating a new design accordingly (Awad and Nassar, 2010). With this ideal case, the conditions for a win-win situation in a coordination concept can be in demand by the parties involve in coordination.

Another vital concept in SCM collaboration can be referred as a process of decision making among interdependent parties as Stank and Keller (2001) mentioned. It involves joint ownership of decisions and collective responsibility for outcomes. Schrage defines it as ‘‘an affective, volitional, mutual shared process where two or more departments work together, have mutual understanding, have a common vision, share resources, and achieve collective goals.’’ Key dimensions are a cross-department (or organization) scope, a commitment to working together, and some common bond or goal.

The adaptation of coordination mechanism to the business process states the degree of integration through supply chain. Arshinder and Deshmukh (2008) define each level (collaboration, cooperation) as a distinct method of coordination. Collaboration is defined as a coordination through at least one of the operations which will change the decision making process from individual to joint management. On the other side, it can be also defined as a joint working approach that requires a broader alignment comparing to cooperation. The broadest concept of all of these concepts can be regarded as a full integration, which refers combining together and forming an internal whole.

The alternate supply chain design mentioned in this thesis can be mainly understood as coordination. Moreover, our point of view also includes a collaborative aspect since it forms the conditions that all entities in supply chain can have benefit. Nevertheless, it needs to be underlined that this structure does not indicate a fully integrated setting.

After listing the positive side of supply chain management concepts it is also essential to discuss about the conceptual misunderstandings and the negative effects of them. Because collaborative relationships may not end with absolute positive effects or a certain success. If organizations cannot give up their ancient operational insights and management philosophies without developing a new point of view the situation can even become worse and worse. The transition process which means changing the management philosophy from a pure competition into a collaborative aspect plays an important role about the success of collaboration. For example, Spekman and Carraway (2006) underline this topic and outline the critical elements in terms of transition process and core drivers of having a sustainable competitive advantage from the collaborative attempts. Daugherty et al. (2006) and Sabath and Fontanella (2002) also underlines that "...supply chain collaboration is at the same time the most used, the most frequently misunderstood, the most popular - and the most disappointing - strategy that has come along to date". Thus, understanding the aspects of collaboration strategy and then managing the transition process effectively is quite vital for organizations.

As we mentioned earlier, supply chain management includes various organizational activities which is a part of the whole operations such as planning, inventory management, purchasing, transportation, handling and so on. Through these activities inventory management is one of the key performance indicators for companies. Since inventory as itself is one of the cost components in supply chain management, its management may make company to save significant amounts or vice versa. Simply, as a mean of inventory it can be regarded as a cash that is stocked in a warehouse. The significance of its management changes from company to company according to the industry dynamics. For example, if inventory itself has a higher unit cost and more volume then inventory management becomes more significant. Because, inventory cost is calculated by multiplying unit cost and its volume on hand and in-transit.

The quality of inventory management and inventory policies a company has a vital impact on corporate profitability and the ability of management to implement its customer service strategies at least total logistics cost as Lambert et all. (1997) refers. Since there is a positive correlation between customer service level and inventory holding amount companies that require high level of customer service level need to have higher inventory level. However, excessive inventory levels can also lower corporate profitability in terms of opportunity of investing on more productive assets and inventory holding cost which is composed of insurance, taxes, storage, obsolescence, damage and interest expenses. For this reason, it is vital for companies to implement cost trade off analysis in order to balance inventory holding cost and customer service level. Moreover, determination of inventory policy is also important for companies in order to have optimum amount of inventory.

In terms of inventory replenishment policies, mainly there are two types of inventory review policies which are continues and periodic review policies. In continues review policy, inventory is reviewed continuously and when the current inventory level reduces to a pre-determined specific level an order should be placed. A well-known policy is *(Q,R)* policy. It is a continuous inventory review system that simply tells to monitor inventory position constantly and when inventory level reduces to level *(R),* Q units are ordered. On the other side, in periodic review systems, inventory levels are checked periodically. The *(s,S)* policy is one of the most common periodic review systems where order up to level *(S)* and inventory position determines order quantity which is not fixed as it is in the case of *(Q,R)* system. In *(s,S)* policy, s represents ROP and after inventory position is less than or equal to this level an order is placed with an amount of S - inventory position. In both review strategies, two main questions are tried to be answered which are when to order and how much to order.

Throughout our study, we use continues review inventory policy with *(s,S)* system where *s* represents ROP and *S* represents the order up to inventory level. In this inventory policy, when on hand inventory reduced under the ROP (*s)* level, order quantities are determined by subtracting on hand inventory level from *S* value. Calculation of optimum little and *S* values are not straight forward instead they require complex mathematical calculations. While calculating these values we use a smart excel spread sheet which find out optimum order amount values by considering various variables.

2.2 Supply Chain Network Design

Globalization triggers organizations towards competitive environment where global supply chain players take part. In this tough environment companies are struggling with each other in order to gain a competitive advantage through their competitors. This severe competition necessitates companies to view their current internal and external business environment and processes. As Thomas and Griffin (1996) refers tough competition make re-evaluation of current supply chain design for many companies operating globally essential in order to check cost effective opportunities are valid to take. In this respect, reviewing the whole supply chain structure which is composed of different organizations from various supply chain layers such as suppliers, manufacturers, wholesalers, distributors and retailers is quite vital. During this review and control of process that takes part between different entities a collaboration between entities is quite necessary as discussed during chapter 2.1. Supply Chain Management section before.

One of the main motivations of supply chain re-design is economical aspect where total supply chain cost is generally measured and optimized. In terms of total supply chain cost there are various cost components such as inventory holding cost, order processing cost, purchasing cost, transportation cost, custom related costs and warehousing costs and so on. Any decrease that is achieved among these cost components will result significant profit increase due to the profit leverage effect of logistics mentioned by Lambert (1998). Out of these cost components all of them are covered through this study by including these cost components as an input of simulation model.

There are various types of supply chain design problems which aim to support decision taking in terms of the number and location of production facilities, the amount of capacity at each facility, the assignment of each market region to one or more locations, and supplier selection for sub-assemblies, components and materials (Chopra and Meindl, 2004). Through the literature one of the fundamental supply chain design issue is outsourcing manufacturing to offshore supplier locations. This issue i.e. supplier selection decision problems changed global supply chain design problems fundamentally (Meixell, Gargeya, 2005). In these problems suppliers are generally selected according to buyer's perception of the supplier's ability to meet quality, quantity, delivery, price and service requirements of the company (Leenders et al., 2002). Another emerging issue through supply chain design is integration of decisions through supply chain partner which affect the whole chain directly. There are many applications in practice such as Vendor Managed Inventory (VMI) and Collaborative Planning, Forecasting, and Replenishment (CPFR) integrate replenishment planning between supply chain entities by sharing sales and promotion information (Sherman, 1998; Lewis, 1999). Many authors (Dornier et al., 1998; Brush et al., 1999; Trent and Monczka, 2003) also mentioned the significance and need for integration between supply chain entities. In addition to discussed supply chain design issue it is obvious supply chain cost reduction objective is the one which is studied mostly both by academicians and industry practices. There are different types of models that aim to minimize total logistics cost by using a different methodology or modeling concept. For example, Supply Chain Operations Reference (SCOR) model defines that; performance through supply chain can be measured in terms of reliability, responsiveness, flexibility, cost and assets (Supply Chain Council, 2003).

On the other side, a considerable portion of the studies in the literature regarding supply chain network design are very much similar to strategic supply chain planning (Vidal and Goetschalckx, 1997; Simchi-Levi et al., 1999; Meixell and Gargeya, 2005; Altıparmak et al., 2006; Chopra and Meindl, 2007). Supply chain planning literature can be classified by two main perspectives that are strategic and tactical/operational (Shen, 2005). Strategic level studies mostly consider the decisions on locating, opening or closing a facility as well as with the decisions on determining the number, capacity and technology requirements of those entities. Göçer (2010) on the other side, distribution and inventory management and transportation related operations are considered as being at tactical and operational levels. However, each level decision need to be evaluated in an integrated manner in order to have a well operated supply chain structure. For example, the objective of Sousa's et al. (2008) was providing a decision support tool for long term investments and strategies over a real industry case with both strategic and operational levels by optimizing production and distribution systems. Similar to this study, Thanh et al. (2008) provides a tool for strategic and tactical decisions for a company foreseeing to expand in volume in a multi echelon, multi commodity production-distribution network system with deterministic demand. The inspiration of this thesis i.e. Göçer (2010) study is dealing with an industrial problem and modeling multi echelon, multi product items with deterministic demand and lead time with an aim of decreasing total logistics costs and illustrating cash flow advantage of their alternative hub included design.

Until this point, supply chain design literature has been shortly discussed. Similar to Göçer (2010) study, our study in this thesis is covering both strategic and tactical/operational insights since it involves both alternate hub included design alternative and inventory management concepts with an aim of decreasing total logics cost. What is new in this study is covering uncertainty in demand and lead time which also take place in real life case. Uncertainty in supply chain design is neither too new nor too former concept through literature. It is one of the hot topics in supply chain design which is divided into two through the literature as using variable operational parameters such as demand and lead time and using uncertainty in exchange rates which is quite common. As Carter (1988), Vickery (1989), Dornier et al., (1998). However, exchange rate stochasticity is out of scope for this study.

There are various papers through literature which are focusing on multi-objective problems, stochastic optimization, two phase optimization and location problems under uncertainty. In terms of location problems, uncertainty is defined with two different ways that are probability or scenario based. These location problems handles issues with a different methodology such as minimum expected cost, mean variance, regret or min-max regret models. For example, Snyder et al. (2007) study include stochastic location model with risk pooling (SLMRP) that optimizes location, inventory and allocation decisions under random parameters described by discrete scenarios. In that study, the objective is the minimization of expected total cost including location, transportation and inventory holding costs. Their location model explicitly handles the economies of scale and risk pooling effects that result from consolidating inventory side. They presented a Lagrangian-relaxation-based exact algorithm for the SLMRP. Covering the economies of scale and risk pooling effects by consolidating inventory side is also in the scope of our study.

Noyan (2010) is about alternate risk measures for emergency service system design also covers stochastic optimization. In that study, demands for emergency medical service is random and she allowed to have unsatisfied demand in the environment by determining target service levels for each demand side and for the entire service area specified. She had presented demands by random variables and also used scenario approach to characterize the randomness. Moreover, in that study integrated chance constraints and stochastic dominance constraints were used. Similar to Lawrance (1977) variable transportation costs, set up cost of opening a facility and total cost of purchasing and maintaining vehicles were minimized and as a last step a heuristic was used in order to finalize study.

Santoso et al. (2005) includes a stochastic programming approach for supply chain network design under uncertainty where the weak part of the existing studies about supply chain network under uncertainty in terms of number of scenarios and uncertain parameter sizes illustrated. The contribution of that study is including high quality solutions with a quick time while computing solutions out of huge number of uncertain scenarios. Sample average approximation (SAA) scheme with accelerated Benders decomposition algorithm is used in that study in order to compute huge number of scenarios in a quicker manner. A computational study takes part in the study for two real supply chain networks under uncertainty cases that enable them to illustrate their new methodology.

In terms of two phase optimization studies Merkuryeva and Napalkova (2007) where both analytical and simulation models takes place can be analyzed. In that paper analytical techniques are used in order to obtain initial planning decisions under conditions of stochastic demand and lead time, whereas simulation techniques extend these conditions to backlogging and capacity constraints. Furthermore, as a second step simulation is used to analyze and improve cyclical decisions received from the analytical model.

With respect to location problems, p –median problem with uncertainty plays an important role through literature. Serra and Marianov (1998) study which is related with p-median problem include a real life case of fire station in Barcelona. They formulated a p-median model to address the issue of new facilities by considering demand and travel time uncertainties. Several possible future scenarios with respect to demand and/or travel time parameters are presented and tried to create a strategy of positioning out of possible future scenarios.

Through the literature we observed that uncertainty in supply chain can be handled with two basic options by using a mathematical model which are scenario and probabilistic approach. Generally, scenario approach discretizes uncertain parameters into a limited number of specified scenarios while probabilistic approach uses stochastic programming. Within the spectrum of studies that handles uncertainty, the most vital and extensive studies are dealing with demand uncertainties (Gupta and Maranas, 2000; Petkov and Maranas, 1998; Ierapetritou and Pistikopoulos, 1996; Liu and Sahinidis, 1998).

Similar to those studies, our model also includes demand uncertainty as a main uncertain parameter where demand is exponentially created and normally distributed with a specific mean and standard deviation. The normality assumption is widely invoked in literature (Wellons and Reklaitis, 1989; Nahmias, 1989) since it covers the essential features of demand uncertainty, and convenient to use. In addition to demand uncertainty, our model also includes lead time uncertainty with the same logic of demand’s normal distribution. In terms of demand uncertainty in our model we do not only use a normally distributed demand but also scenario approach is followed through various scenarios such as low, moderate, high demand and standard deviations where all demand and standard deviation pairs are used with totally 9 different scenarios. By including these uncertainties parameters and alternative scenarios our model is able to replicate real life uncertainties as much as possible.

2.3 Supply Chain Simulation

Supply chain simulation is not a new concept in the literature since simulation is one of the alternative ways to re-design supply chain by constructing and measuring alternative designs in terms of a strategic or tactical/operational insight. In practice, simulation is a method that is relatively often used as compared with other quantitative models. As Kleijnen (2005) mentioned in his study several reasons may explain this popularity: no mathematical sophistication is needed, multiple responses are natural in simulation (in SCM, these responses may be the fill rate or service percentage, stocks including work in progress, sales, etc.). These various aspects are also discussed by Gunasekaran, Patel and McGaughey (2004) and Kleijnen and Smits (2003).

In Kleijnen (2005) three characteristics of a simulation model are descripted as:

- A quantitative, mathematical, computer model,
- A dynamic model; i.e., it has at least one equation with at least one variable that refers to at least two different points in time,
- A simulation model is not solved out by a mathematical analysis; instead, the time paths of the dependent variables (outputs) are calculated, given the initial state of the simulated system, and given the values of the exogenous (input) variables.

Simulation supports decision making in supply chain management (SCM) at mainly two levels which are the strategic and operational levels. Strategic point of view may include broader perspective which are discussed and controlled by a top level decision maker in the organization such as supply chain design or facility location decisions whereas operational view supports minor daily activities which are decided by a mid-level managers such as transportation policy or inventory holding levels. These levels can be simulated by a simulation tool by using different simulation types. As Kleijnen and Smits (2003) refer there are four different simulation types for SCM that are spreadsheet simulation, system dynamics (SD), discrete-event dynamic systems (DEDS) simulation, and business games.

The introduction of spreadsheet software where corporate modeling firstly introduced starts with Plane, 1997 and Powell, 1997. A simple example of an equation that is easy to program through a spreadsheet can be simply referred with an equation as:

new inventory = old inventory + production – sales.

This type of simulation has been used to apply manufacturing resource planning (MRP), which is an important subsystem of SCM; (Sounderpandian, 1989). A recent spreadsheet model of vendor managed inventory (VMI) in supply chains is presented in Disney and Towill (2003).

The second type i.e. system dynamics (SD) simulation may explain the bullwhip effect. Firstly, Forrester (1961) developed industrial dynamics, that he later extended it and called system dynamics (SD). The supply chain he mentioned has four links which are retailer, wholesaler, distributor and factory. He examines how these links react to deviations between actual and target inventory levels and finds that ‘commonsense’ strategies may amplify fluctuations in the demand by final customers, up in the supply chain. Later, Lee, Padmanabham and Whang (1997) identified this amplification as one of the bullwhip effects; see also Disney and Towill (2003).

From a methodological viewpoint, SD views companies as systems with six types of flows, namely materials, goods, personnel, money, orders and information. SD assumes that managerial control is realized through the changing of rate variables (for example, production and sales rates), which change flows, and hence stocks. A crucial role in the SD worldview is played by the feedback principle; i.e., a manager compares a target value of a specific performance metric with its realization, and— in case of undesirable deviation—the manager takes corrective action. An example equation is:

$$\text{Inventory.K} = \text{Inventory.J} + \text{DT} * (\text{Production\_rate.JK Sales - rate.JK})$$

where Sales_rate.JK denotes the sales rate during the interval between the points of time J and K; DT denotes the length of that interval; etc.

The third simulation type i.e. a discrete-event dynamic system (DEDS) simulation is more detailed than the preceding two simulation types. Firstly, DEDS simulation has the following two characteristics:

- It includes individual events (for example, the arrival of an individual purchase order)
- It handles uncertainties (for example, purchase orders arrive at random points in time, production break down at random points of time etc.)

The other three types of simulation models can also handle uncertainty and randomness. However, most SD models have no randomness, and yet their behavior remains counter-intuitive because of the nonlinear feedback loops. See Gaonkar (1977). DEDS simulation is an important method in SCM. For example, Banks et al. (2002) survey SCM simulation studies, at IBM and Virtual Logistics, and they discuss strategic and operational SCM, distributed SCM simulation, commercial packages for SCM simulation, etc. Indeed, DEDS simulation is already part of the MRP/ERP toolbox for quantifying the costs and benefits of strategic and operational policies (ERP: Enterprise Resource Planning); For a detailed discussion, we refer to Vollmann, Berry and Whybark (1997).

Business games are relatively easy to simulate technological and economic processes, but it is much more difficult to model human behavior. A solution is to let managers themselves operate within the simulated ‘world’, which may consist of a supply chain and its environment. Such an interactive simulation is called a business or management game. Games may be used for both educational and research goals. For their education usage, we refer to Riis, Smeds and Van Landeghem (2000) and Ten Wolde (2000). For research usage, we refer to Kleijnen (1980). For example, Kleijnen (1980, pp.157–186) uses an IBM management game to quantify the effects of information accuracy on return on investment (ROI). Another example is the use of games to study the confidence that managers have in their decisions. Kleijnen and Smits (2003) and Riis, Smeds and Landeghem (2000) are more recent studies on this topic.

Throughout these simulation types the logic of our simulation model is a discrete-event dynamic systems (DEDS). The main logic of our simulation model is inventory management where a simple equation takes place as:

Inventory position = physical inventory + in transit inventory

where the physical inventory is decreased when a demand enters in the system. Similarly, when physical inventory is reduced under a certain ROP level an order is released and in transit inventory is updated. After a specific lead time physical inventory level is updated and the system continues in the same manner. On the other hand, our system includes uncertainty i.e. randomness where random and normally distributed demands are entering into the system. After these demands are created they are deducted from the inventory level which refers the usage of those raw materials in the production. Since individual random demands are released into the system with MRP logic, the simulation type of this study can be defined as DEDS.

From a methodological point of view, Kleijnen (2005) defines four types of concepts in simulation for SCM as (i) validation and verification, (ii) sensitivity or ‘what-if’ analysis, (iii) optimization and robustness, (iv) risk or uncertainty analysis. To address these four methodological issues, a variety of techniques may be used. However, we have focus on the use of statistical methods for the design of experiments (DOE). DOE is important in simulation, because, by definition, simulation is an experimental method; i.e., the analysts experiment with different input values and different model structures (representing different policies, etc.) of the simulation model.

Simulation is a good methodology which gives an understanding into the causes and effects of the supply chain performance: ‘‘which inputs significantly affect which outputs?’’ By using a modern simulation software it is quite easy to replicate the real environment such as supply chain systems with great operational details.

Through the literature there are many different examples where modern simulation software which enable modelling individual events such as order arrivals and machine breakdowns in great detail; see Kelton, Sadowski and Sturrock’s (2004) manual for simulation in the Arena software. Vamanan et al. (2004) compare Arena and other ‘commercial off the shelf’ (COTS) software; Biswas and Narahari (2004) present object-oriented software for simulation models and other model types of supply chains.

It is obvious that re-design of supply chain and its operations may result with a great saving for companies. For example, Banks et all. (2002) discussed about the significance of supply chain re-design by introducing a new supply chain simulation tool which is named as Asset Management Tool (AMT). By using this tool IBM reengineered its global supply chain to achieve quick responsiveness to its customers with minimal inventory. With the contribution of AMT IBM has managed to save over $750 million in material cost and price protection expenses in 1998. After this incredible success IBM received the prestigious Franz Edelman award from INFORMS in 1999 (Lin et al. 2000). Later on, AMT was made into an IBM product called supply chain analyzer (SCA) that was used in consulting parties by IBM Global Services. (Bagchi et al. 1998)

What this simulation tool i.e. AMT can achieve is quite satisfied. It can provide alternative supply chain structures by providing number and location of manufacturers and DC's and their stock level for each product. Moreover, it provides alternative manufacturing and replenishment policies such as Build to Order or Build to Plan. What is more this tool is able to provide both transportation and supply policies with by considering lead times, supplier performance and demand variability. Banks et all. (2002) are focusing on the integration of operational simulation designs with the enterprise IT system which is quite essential for the customized needs of each customer i.e. company. What is more, their simulation tool is web enabled which means all the data is available on the web.

In terms of supply chain simulation most of the models trough literature includes the simulation of material flow which is the main purpose of supply chain simulation. Most of these models include a number of integrated manufacturing and logistics modules where the materials are flowing through. The simulation model we construct has also a similar concept with a purpose of managing the flow of materials through supply chain entities which are suppliers, supply hubs and manufacturers. The model we built includes two echelon, multi commodity and multi plant system which starts with an individual order of manufacturer for a specific item and ends with supplying of this item from supply hub or supplier at the end. On the other side, there are some advance supply chain simulation models which own integrated models of manufacturing and logistics systems that are including sub models of the business processes and information flows in addition to the material flow. Such holistic models are referred by (Jain et al. 2002) as Virtual Factory and Virtual Logistics.

Similar to preceding studies regarding supply chain simulation our model can measure the performance of different supply chain stage of the supply chain under various established desired inventory levels. This measurement is fulfilled under an uncertain environment where the lead time is variable and the demand is randomly generated with a normal distribution. Our model also enable After supply chain partners set service level goals i.e. the portion of demand satisfied by on hand inventory and put the related data into the simulation model they are able to review the performance of established system within a few minutes as if years are passed. By reviewing the inventory levels and related costs strategic, tactical or operational decisions can be made by industry. By changing the operational or tactical variables in the simulation more successful decisions can be taken in order to achieve corporate short and long term goals.

2.4 Inventory Management via Simulation

Among all quantitative methods, simulation is undoubtedly one of the most powerful techniques to apply, as a decision support system, within a supply chain environment. In the industrial area, simulation has been mainly used for decades as an important support for production engineers invalidating new lay-out choices and correct sizing of a production plant as Brooks (2001) give an example of it. As Kosturiak (1999) refers, nowadays, simulation knowledge is considered one of the most important competences to acquire and develop within modern enterprises in different processes (business, marketing, manufacturing, etc.). Several organizations consider simulation as an essential decision support system, for example since 1996 the USA Department of Defense (DoD) has been asking to all its services and parts suppliers to furnish a simulation model of the product or service provided.

Simulation as a tool can be applied to many supply chain related issues such as supply chain network design, supply chain strategic decision support tool, demand and sales planning, distribution and transportation planning, production planning and scheduling and inventory management. In terms of these issues we use simulation technique for supply chain network design and inventory management aspect in the same time through this thesis. Supply chain related simulation examples were given in section 2.3 with supply chain simulation section. Thus, it is more suitable to elaborate on inventory management via simulation with the upcoming examples.

In terms of inventory management, the most common way is using mathematical modeling technique. However, the root of simulation modelling is not a new concept through the literature. Models for optimizing inventory management decisions have been proposed and applied for over 60 years. As a milestone idea firstly, Forrester (1961) suggests that the success of industrial companies depends on the interaction between the flows of information, materials, orders, money, manpower, and capital equipment and states that the understanding and control of these flows is the main task of management. With the introduction of his new way of thinking in business, system dynamics modelling begins to take attraction through the literature. For example, Akkermans (1999) uses dynamics modelling in international supply chain management was used. Similarly, as a basis of new decision making process in inventory management process, Sterman (1989) presents a generic model of stock management system. This generic stock management structure is applicable to many different scenarios, including raw material ordering, production control, or at a macroeconomic level, the control of the stock of money. The model consists of two parts, the physical stock and flow structure of the system, and the decision rules used to control the system.

Furthermore, Barlas and Aksogan (1997) use a case study in the apparel industry to develop a system dynamics simulation model of a typical retail supply chain, in this case a three-echelon chain consisting of manufacturer, wholesaler, retailer and end customer. The purpose of their simulation exercise is to develop inventory policies that increase the retailers’ revenue and at the same time reduce costs. Using a commercially available SD modelling environment, they develop a simulation model of the apparel supply chain. The model represents the physical structure of the system and also incorporates ordering and production decision rules. Numerous simulation runs are carried out, testing different ordering and production policies under various inventory levels and demand patterns. Barlas and Aksoğan (1997) find that order policies as used in continuous systems are not adequate for partially discrete, partially continuous inventory systems. The outcome of the modelling efforts then leads to the proposition of new ordering policies for partially continuous, partially discrete inventory system, which are robust in terms of fluctuations in demand.

In addition, Monte Carlo simulation technique is also one of the important methods in the literature. This technique relies on repeated random sampling to obtain numerical results; typically one runs simulations many times over in order to obtain the distribution of an unknown probabilistic entity. This method is mostly used when it is quite difficult to obtain a close form mathematical expressions. For example, Marcikic (2009) follows this technique where the main goal is to determine how randomness, errors of lack of knowledge affect the performance and reliability of the system. Similarly, from another perspective, Fleisch (2005) uses the same simulation technique in order to compare physical and system inventory levels and illustrate how inventory inaccuracies cause overall supply chain cost loss.

Throughout the literature there are also differentiated service inventory problems where several decision policies applied for different customer groups such as highest priority customers or the lowest ones. One such decision policy is called Critical Level Policy with $n-1$critical levels for n customer groups. It is assumed that demand from the customer with the highest priority will always be satisfied. When demand from class m arrives, it will be satisfied if the inventory-on-hand is higher than the j^{th} critical level; otherwise, it would be rejected. Veinott (1965) was the first to consider such inventory policy under periodic review. Similarly, Dekker, Hill and Klejin (1998) applied it in a lost sales continuous (s,Q) model.

Although the simulation logic of our study resembles some of the simulation related supply chain design and inventory problems which covers operational or strategic insights, it has a distinct point of view in terms of model setup. Because, in most of the studies published before there are various different setups either just follows re-designing a supply chain as a strategic manner or handling tactical or operational inventory management task. However, our model has two different capabilities by following what if scenario logic. I mean that, we are both dealing with constructing a new supply chain design which is a strategic insight and fulfilling the operational inventory management process of the whole supply chain. Thus, this model provides a different point of view to the simulation technique where a various strategic, tactical or operational tasks can be achieved at the same time.

CHAPTER III

CURRENT SUPPLY CHAIN STRUCTURE OF THE COMPANY

Throughout this chapter there are mainly three different sections. First of all, current business procurement model of the mentioned company has been analyzed. The main cost components of this structure has been discussed with typical examples and cost tables. Finally, main setting in simulation model and cost formulations fulfilled for this model has been illustrated via examples.

3.1 Current Business Procurement Model

As it is discussed before the main goal of this thesis is designing a new supply chain network for a multinational company under uncertain parameters and considering the possible opportunities of this alternate structure in terms of demand fill rate and total logistics cost. For this reason, first of all, by using simulation modeling technique we design the current supply chain of the company and measure its outcomes in order to compare it with the alternate designs. Through this aspect it is necessary to discuss a little on the current (traditional) supply chain structure of the mentioned multinational company.

In the traditional supply chain of the company there are suppliers, manufacturers and distributers as business entities. As a manufacturing party in supply chain the main inventory, information and cash flows are taking part between manufacturers - suppliers and manufacturers - distributors. The manufacturing party has several production centers which are located in different geographical regions of the world. These manufacturing sites are clustered in region based where all regions are controlled by the lead manufacturing plants. Each region has a specific target to produce, distribute and sell its finished goods and contribute each other when it is necessary. Similarly, each manufacturing site has a specific region where all finished goods are pushed towards the shelves in order to be ready for the purchase of final consumer in the market. In terms of inbound part of supply chain, manufacturing entities are supplied by the various suppliers which are located geographically different areas in the world. Suppliers are not only selling their finished goods to this company but also other companies that operate in the same sector.

Current business procurement model of this multinational company is structured by the creation of individual purchase orders by each manufacturer directly to the related suppliers. For this reason this procurement structure is a typical single-echelon system which is composed of suppliers and regional manufacturers. Each party keeps its safety stocks on its site and these safety stock levels are determined by the parties themselves according to their own inventory management strategies. The following figure 3.1 demonstrates the main inbound inventory flow in the traditional model.

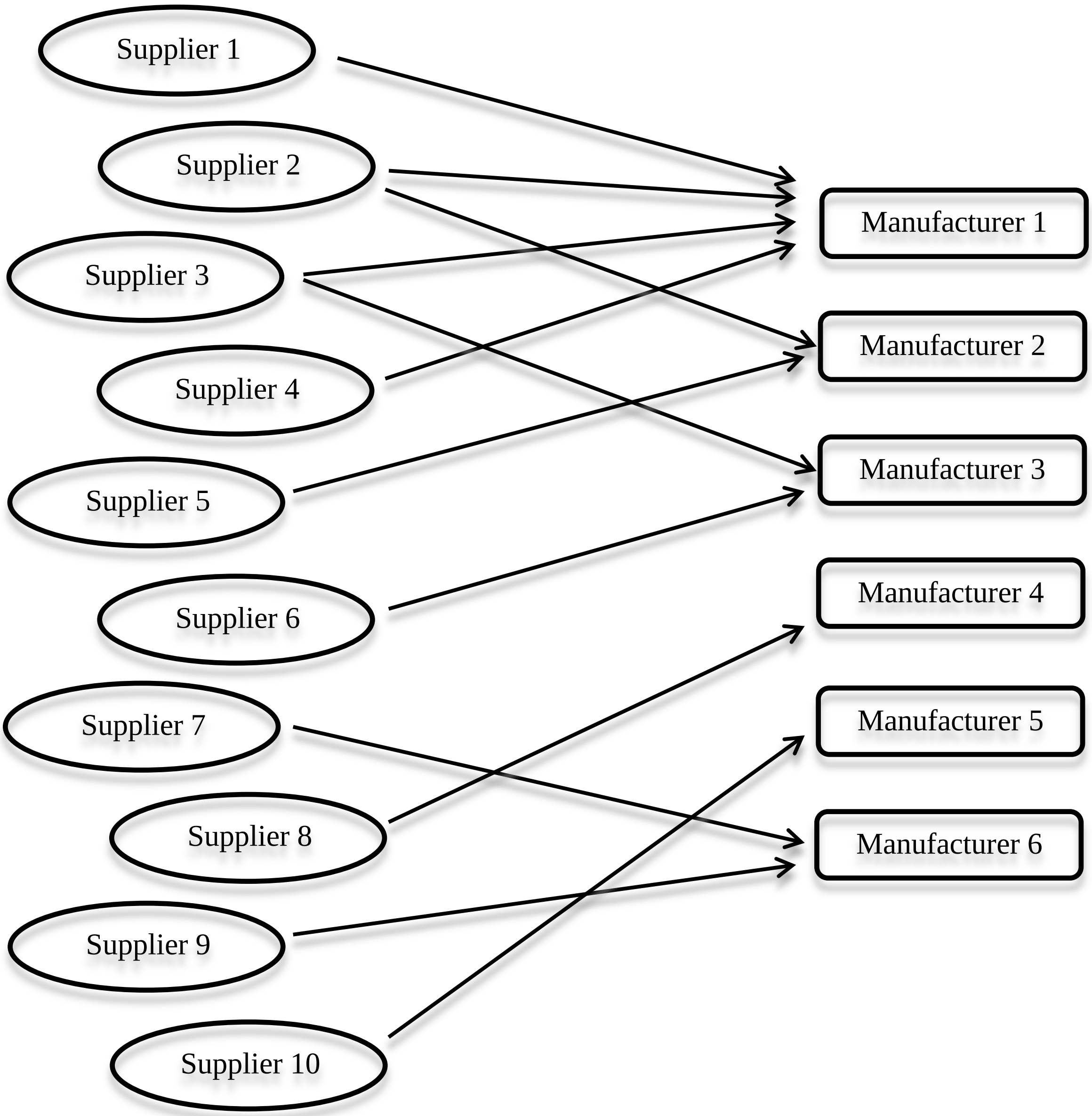


Figure 3.1: Inbound Inventory Flow in Traditional Model

In the real life, the procurement process starts with a need of material which is triggered by manufacturers' demand for a stock keeping unit (SKU). After a demand for a specific SKU is received from the market, production and planning departments check the on hand inventory levels and determine necessary material amount by issuing related purchase requisitions (PRs). After purchasing department receives a PR created according to the need of a specific material, it is sent to the related supplier by issuing purchase orders (POs). Moreover, as it is the same in the most of the real life cases demands are unknown. After purchase orders are received by suppliers, they check their inventory level and provide related order confirmation to manufacturer. After this process, a shipment date and carrier are determined by manufacturer and supplier check and confirms it by releasing the materials on the shipment date. As a final section, transportation starts and after a specific lead time materials arrives to custom clearance point. Finally, they are transferred to manufacturers' own warehouses.

With respect to this real life case we tried to follow the same logic in the simulation model. A specific region is selected out of several regions and most commonly used materials and their related suppliers are covered through the thesis. Table 3.1 represent the list of manufacturers, items and suppliers with their simulation model code specified in our simulation model. All item-manufacturer and item supplier matches represent the real case of the company. As it is figured out from Table 3.1 each manufacturer has several specific material types and these manufacturers are only using these items in order to build a finished good in their premises. For example, manufacturer located in Turkey is using 7 different materials while Jordan and Tanzania manufacturers have only 3 different items.

Table 3.1: List of Manufacturers, Items and Suppliers with Unique Model Codes

Manufacturer (Plant)	Plant code	Product (Item)	Item code	Location of supplier	Supplier Code
Turkey	1	CP_1	1	FRANCE	1
Turkey	1	CP_2	2	AUSTRIA	2
Turkey	1	CP_3	3	USA	3
Turkey	1	FT_1	5	TURKEY- W/H	4
Turkey	1	PP_1	9	GERMANY	5
Turkey	1	PP_2	10	UK	6
Turkey	1	PP_3	11	ITALY	7
Tunisia	2	CP_4	4	SPAIN	11
Tunisia	2	FT_1	5	TURKEY- W/H	4
Tunisia	2	FT_4	8	USA	3
Tunisia	2	PP_3	11	ITALY	7
Tanzania	3	CP_4	4	SPAIN	11
Tanzania	3	FT_2	6	JAPAN	9
Tanzania	3	PP_4	12	MALAYSIA	10
S. Africa	4	CP_2	2	AUSTRIA	8
S. Africa	4	FT_2	6	JAPAN	9
S. Africa	4	FT_3	7	UK	6
S. Africa	4	PP_4	12	MALAYSIA	10
Jordan	5	CP_4	4	SPAIN	11
Jordan	5	FT_2	6	JAPAN	9
Jordan	5	PP_4	12	MALAYSIA	10
Iran	6	CP_1	1	FRANCE	1
Iran	6	CP_4	4	SPAIN	11
Iran	6	FT_2	6	JAPAN	9
Iran	6	PP_4	12	MALAYSIA	10

Furthermore, items supplied from various suppliers have a unique purchasing cost for manufacturers as illustrated in Table 3.2. Similarly since the specification of these materials differs from each other their volume and weights are changing too. In order to calculate transportation cost of these items truck load logic is used in simulation model. Both full truck load (FTL) and less than truck load (LTL) cost are being calculated based on the capacity a truck can carry for each item. Table 3.3 shows the amount of item a full truck or container can carry.

Table 3.2: Purchasing Cost of Items

Item	Purchasing Cost per Unit
1	$30
2	$30
3	$30
4	$30
5	$5
6	$5
7	$5
8	$5
9	$30
10	$30
11	$30
12	$30

Table 3.3: Truck Size of Items / kg

Item	Truck Size
1	4.608
2	4.080
3	4.608
4	4.080
5	18.000
6	18.000
7	18.000
8	18.000
9	2.240
10	1.920
11	2.240
12	2.240

In terms of safety stock level at the supplier side, suppliers hold their inventories according to manufacturers’ demand ratios. Generally, as we are informed by industry advisors, suppliers are keeping 1,5 month demand of manufacturers in their facilities.

On the other side, manufacturers have a specific transportation lead time for each material supplied from different suppliers as illustrated on a daily basis for each manufacturer and item in Table 3.4 below. In our model, lead times are assumed to be normally distributed with a standard deviation of 10%. This enables to cover real life cases where a truck or vessel can be unloaded a few days earlier or later. In terms of lead time uncertainty this standard deviation level is quite fair unless extraordinary circumstances such as vessel sunk or truck fire cases involve in. Moreover, these lead times are not only used as uncertain transportation lead time variables but also to calculate lead time demand of each material for each manufacturer while ROP are being calculated.

Table 3.4: Lead Time between Supplier and Manufacturers for each Item / (Day)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Turkey	14	28	42	0	1	0	0	0	14	21	7	0
Tunus	0	0	0	42	14	0	0	56	0	0	28	0
Tanzania	0	0	0	56	0	56	0	0	0	0	0	42
S. Africa	0	49	0	0	0	49	49	0	0	0	0	42
Jordan	0	0	0	42	0	42	0	0	0	0	0	35
Iran	21	0	0	42	0	35	0	0	0	0	0	28

As a process of inventory management, our model follows a systematic logic which is composed of several tasks as it in the real life case. First of all, demands of manufacturers as an attribute in simulation are incurred with a normal distribution on a weekly basis with a specific standard deviation. After demand creation, simulation model checks the physical inventory level and decide whether there is a need for releasing a purchase order or not. If on hand inventory level is sufficient then after physical inventory and inventory position levels are updated by subtracting demand amount from each of them the entity exits from the system. On the contrary, if the demand is less than the physical inventory level on hand inventory is used to satisfy some portion of the demand. In this case physical inventory becomes zero automatically. Similar to previous case, inventory position which is composed of as a summation of physical inventory and in transit inventory levels is again updated. The reason of keeping and updating inventory position variable is that purchase order creation times of manufacturers are decided by checking this variable. On the other hand, order amounts are determined by the simulation model with an s, S inventory management policy logic which says give an order when inventory position level is equal to *s* (ROP) or less than under *s* (ROP) with an amount of *S* - inventory position. In the current business structure in terms of inventory management there are five different variables which determine purchase order amount and time. These variables are as follows:

inventory(plant,item) Current inventory level of a specific item and manufacturer.

in transit inventory(plant,item) Inventory level of manufacturer which is in transit.

Equation 3.1 shows the calculation of inventory position in simulation model.

Equation 3.1

Inventory position(plant,item) = Inventory(plant,item) + in transit inventory(plant,item)

Little_s(plant,item) ROP kept at manufacturer for an item

Big_S(plant,item) Order up to inventory level (Maximum amount of material that is required to be held by manufacturer

Re-order levels (*s* values) are calculated for each item and scenario by considering lead time demand, standard deviation and inventory holding policy. For example, if weekly demand is equal to 1923, lead time is 7 weeks, standard deviation is 10% and safety stock policy is lead time demand plus one month (company policy re-order level). Then, by using below equation 3.2 we obtain *22.315* value.

Equation 3.2

Little_s(plant,item) **= [Demand(plant,item) * (Lead time(plant,item) + 1 month)] + [**$\sqrt{\boldsymbol{Lead\ time(plant, item)}}$ *** Demand(plant,item) * Standard deviation]**

Another important point while determining purchase order amount is Q* which represents the optimum order quantity. This quantity is calculated for each manufacturer and item by considering their annual demand, standard deviation of annual demand, lead time, ordering cost, inventory holding cost, purchasing cost, annual interest rate and stock out cost with a clever excel calculation sheet. An example of data set used to calculate *Q** value is shown with Table 3.5 below.

Table 3.5: Data Set Used to Calculate Optimum Ordering Amount (Q* Values) of Manufacturers in Tradition Structure

Parameters	**Notation**	**Value**
Ordering Cost ($)	K	202
Wekly demand	L	14.423
Standard deviation of weekly demand	sa	1.442
Purchase price($)	c	5
Interest rate (weekly)	I	0,15%
Holding cost per unit, per week ($)	h	0,0014
Lead time (week)	T	4,5
Penalty cost ($)	p	5
Lead time demand	u	64.904
Lead time standard deviation	s	3.060

By using the parameters illustrated with Table 3.5 optimum order amount (*Q** value) which has a value of *65.514* is calculated. This excel spread sheet is design to calculate optimum Q and R values where the total cost is minimized in *(Q,R)* policy. This *Q** values are updated when lead times and standard deviations are updated with an involvement of alternative supply chain scenarios. On the other side, Q^* values directly affect order up to S values when s (re-order point) values are updated with different service strategies (company policy, 90% and 98% service levels). Since S value is the summation of s and Q^* as it is illustrated in Equation 3.3, in each scenario S values alter directly.

Equation 3.3

$$Big\_S(plant,item) = little\_s(plant,item) + Q^{*}(plant,item)$$

As it is mentioned in the methodology section there are different values of s (ROP) and S (up to order level) covered in this study. Since various scenarios are studied with different customer service levels such as company policy (Lead time demand + 1 moth inventory level), inventory level with 90% service level where 90% of the normally distributed demand is satisfied from the stock and with the same logic 98% service level. For each of these scenarios a specific ROP (s) and order up to level (S) are obtained. For clarification, Table 3.6, Table 3.7 and Table 3.8 illustrate different ROP (s) for each service level under medium and normally distributed 10% standard deviation demand while Table 3.9, Table 3.10 and 3.11 indicate matching order up to levels (S values) respectively under the same scenario. It necessary to mention that in each scenario out of 81 ones, there is a unique s, Q^* and S sets which are calculated according to a specific service level, standard deviation ratio, demand rate (low, medium and high) and supply chain design (without hub, one hub, two hub structures) scenario.

Table 3.6: ROP (Little_s) Values under Company Policy, Medium Demand and 10% Standard Deviation in Tradition Structure

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	18.390	6.228	2.032	0	209.227	0	0	0	2.459	918	721	0
Tunus	0	0	0	2.088	2.088	0	0	46.817	0	0	369	0
Tanzania	0	0	0	12.204	0	152.666	0	0	0	0	0	1.639
S. Africa	0	3.672	0	0	0	27.581	18.390	0	0	0	0	486
Jordan	0	0	0	6.567	0	82.112	0	0	0	0	0	864
Iran	9.190	0	0	8.206	0	180.602	0	0	0	0	0	1.866

Table 3.7: ROP (Little_s) Values under 90% Service Level, Medium Demand and 10% Standard Deviation in Tradition Structure

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	10.165	2.095	1.212	0	43.384	0	0	0	1.225	507	309	0
Tunus	0	0	0	433	433	0	0	27.924	0	0	124	0
Tanzania	0	0	0	7.279	0	91.060	0	0	0	0	0	817
S. Africa	0	2.029	0	0	0	15.245	10.165	0	0	0	0	242
Jordan	0	0	0	3.272	0	40.921	0	0	0	0	0	370
Iran	5.080	0	0	4.090	0	77.443	0	0	0	0	0	628

Table 3.8: ROP (Little_s) Values under 98% Service Level, Medium Demand and 10% Standard Deviation in Tradition Structure

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	10.500	2.201	1.248	0	46.383	0	0	0	1.270	524	322	0
Tunus	0	0	0	463	463	0	0	28.769	0	0	130	0
Tanzania	0	0	0	7.499	0	93.815	0	0	0	0	0	847
S. Africa	0	2.096	0	0	0	15.748	10.500	0	0	0	0	251
Jordan	0	0	0	3.392	0	42.421	0	0	0	0	0	386
Iran	5.247	0	0	4.239	0	80.690	0	0	0	0	0	659

Table 3.9: Order Up To (Big_S) Values under Company Policy, Medium Demand and 10% Standard Deviation in Tradition Structure

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	31.222	14.501	6.112	0	314.674	0	0	0	5.552	2.572	2.501	0
Tunus	0	0	0	7.317	12.625	0	0	82.883	0	0	1.738	0
Tanzania	0	0	0	21.325	0	217.276	0	0	0	0	0	4.159
S. Africa	0	8.913	0	0	0	56.910	42.797	0	0	0	0	1.858
Jordan	0	0	0	14.046	0	134.883	0	0	0	0	0	2.811
Iran	18.280	0	0	16.555	0	263.985	0	0	0	0	0	4.954

Table 3.10: Order Up To (Big_S) Values under 90% Service Level, Medium Demand and 10% Standard Deviation in Tradition Structure

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	22.997	10.368	5.292	0	148.831	0	0	0	4.318	2.161	2.089	0
Tunus	0	0	0	5.662	10.970	0	0	63.990	0	0	1.493	0
Tanzania	0	0	0	16.400	0	155.670	0	0	0	0	0	3.337
S. Africa	0	7.270	0	0	0	44.574	34.572	0	0	0	0	1.614
Jordan	0	0	0	10.751	0	93.692	0	0	0	0	0	2.317
Iran	14.170	0	0	12.439	0	160.826	0	0	0	0	0	3.716

Table 3.11: Order Up To (Big_S) Values under 98% Service Level, Medium Demand and 10% Standard Deviation in Tradition Structure

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	23.332	10.474	5.328	0	151.830	0	0	0	4.363	2.178	2.102	0
Tunus	0	0	0	5.692	11.000	0	0	64.835	0	0	1.499	0
Tanzania	0	0	0	16.620	0	158.425	0	0	0	0	0	3.367
S. Africa	0	7.337	0	0	0	45.077	34.907	0	0	0	0	1.623
Jordan	0	0	0	10.871	0	95.192	0	0	0	0	0	2.333
Iran	14.337	0	0	12.588	0	164.073	0	0	0	0	0	3.747

In real life suppliers are also holding safety stock levels which are equal to the summation of one month manufacturer’s demand. According to their policy, since there is a considerable length of transportation lead times between suppliers and manufacturers these safety stocks should be kept at the supplier side. Furthermore, a few suppliers which are located too far away from manufacturers (in USA and Japan located suppliers) are holding more inventory level than one month demand of manufacturers. For this reason, it can be referred that, suppliers have a considerable amount of inventory in the current business structure.

3.2. Cost Components of the Manufacturers in Traditional Structure

In simulation model, as it is in the real life case order amounts are determined by manufacturer itself by reviewing inventory position and demand forecasts. We assume that the agreement between the suppliers and manufacturers is based upon the ex-works sales of the products. In ex-works agreements, the products are delivered to other party at supplier‘s premises and all costs generated then after are owned by the other party. Thus, transportation cost from the suppliers to the manufacturers is incurred by the manufacturers themselves. Besides, invoices for orders are issued by the supplier to the manufacturer as soon as the orders are shipped from the supplier‘s facilities. This then implies that the associated costs during the lead time are incurred by the manufacturer. Through this ordering cycle various cost are generated at the manufacturer‘s side such as transportation cost, inventory handling cost, customs and agencies cost, and ordering cost for each unit and time. There are two types of transportation cost in the model which are full truck load cost and less than truck load costs. LTL costs are 20% more expensive than the FTL costs as it is informed by industry applicants. We have listed these cost details according to manufacturers and items supplied from different suppliers per truck/container as it listed in Table 3.12 and Table 3.13.

Table 3.12: FTL Transportation Cost of Manufacturers from Suppliers / $

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Turkey	1750	2862	2500	0	100	0	0	0	1260	1520	910	0
Tunus	0	0	0	2121	1600	0	0	2878	0	0	2800	0
Tanzania	0	0	0	3240	0	3676	0	0	0	0	0	3450
S. Africa	0	3950	0	0	0	3980	4631	0	0	0	0	3430
Jordan	0	0	0	1626	0	4090	0	0	0	0	0	3100
Iran	2416	0	0	2169	0	2741	0	0	0	0	0	3108

Table 3.13: LTL Transportation Cost of Manufacturers from Suppliers / $

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Turkey	2100	3434	3000	0	120	0	0	0	1512	1824	1092	0
Tunus	0	0	0	2545	1920	0	0	3454	0	0	3360	0
Tanzania	0	0	0	3888	0	4411	0	0	0	0	0	4140
S. Africa	0	4740	0	0	0	4776	5557	0	0	0	0	4116
Jordan	0	0	0	1951	0	4908	0	0	0	0	0	3720
Iran	2900	0	0	2602	0	3289	0	0	0	0	0	3730

There are other cost components such as inventory holding, ordering, custom, back order and unit material costs. Since we focus on the total cost of manufacturers' all cost details which incurs in real life has been covered in the simulation model as well. All these costs except back order cost has been supplied by the company itself for this academic study. This will enable to replicate real life cost occurrence via simulation.

There are other cost components which incurs when a purchase order is created and shipment starts after supplier has been informed by sending the PO. These are ordering cost, fixed cost of ordering and custom clearance related costs. Ordering cost simply refers the cost that incurs per item while ordering. This cost implies the paper or electronic related cost that occurs while ordering. Related cost details are shown in Table 3.14.

Table 3.14: Ordering Cost of Manufacturers per Unit Item / $

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Turkey	0,0014	0,0017	0,0014	0,0000	0,0004	0,0000	0,0000	0,0000	0,0036	0,0042	0,0036	0,0000
Tunus	0,0000	0,0000	0,0000	0,0017	0,0004	0,0000	0,0000	0,0004	0,0000	0,0000	0,0036	0,0000
Tanzania	0,0000	0,0000	0,0000	0,0017	0,0000	0,0004	0,0000	0,0000	0,0000	0,0000	0,0000	0,0036
S. Africa	0,0000	0,0017	0,0000	0,0000	0,0000	0,0004	0,0004	0,0000	0,0000	0,0000	0,0000	0,0036
Jordan	0,0000	0,0000	0,0000	0,0017	0,0000	0,0004	0,0000	0,0000	0,0000	0,0000	0,0000	0,0036
Iran	0,0014	0,0000	0,0000	0,0017	0,0000	0,0004	0,0000	0,0000	0,0000	0,0000	0,0000	0,0036

In addition to ordering cost there is another cost which is fixed for all manufacturers and items that incur in every shipment. This cost can be regarded as fixed shipment cost which is a considerable amount for the company as details are shown in below Table 3.15.

Table 3.15: Fixed Shipment Cost of Manufacturers / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	200	200	200	0	200	0	0	0	200	200	200	0
Tunus	0	0	0	200	200	0	0	200	0	0	200	0
Tanzania	0	0	0	200	0	200	0	0	0	0	0	200
S. Africa	0	200	0	0	0	200	200	0	0	0	0	200
Jordan	0	0	0	200	0	200	0	0	0	0	0	200
Iran	200	0	0	200	0	200	0	0	0	0	0	200

One of the main cost components in traditional business structure are custom related costs which have three different components such as custom cost per shipment, custom cost per truck and custom cost per unit. All of these data are supplied by industry and added into the model directly. Table 3.16 represents custom cost per shipment; Table 3.17 illustrates custom cost per truck and Table 3.18 points out unit custom costs for manufacturers.

Table 3.16: Custom Cost of Manufacturers per Shipment / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,031	0,018	0,003	0,000	0,160	0,000	0,000	0,000	0,010	0,004	0,003	0,000
Tunus	0,000	0,000	0,000	0,007	0,002	0,000	0,000	0,018	0,000	0,000	0,002	0,000
Tanzania	0,000	0,000	0,000	0,021	0,000	0,060	0,000	0,000	0,000	0,000	0,000	0,006
S. Africa	0,000	0,007	0,000	0,000	0,000	0,012	0,008	0,000	0,000	0,000	0,000	0,002
Jordan	0,000	0,000	0,000	0,014	0,000	0,040	0,000	0,000	0,000	0,000	0,000	0,004
Iran	0,016	0,000	0,000	0,018	0,000	0,100	0,000	0,000	0,000	0,000	0,000	0,010

Table 3.17: Custom Cost of Manufacturers per Truck / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,094	0,053	0,009	0,000	0,481	0,000	0,000	0,000	0,029	0,011	0,010	0,000
Tunus	0,000	0,000	0,000	0,021	0,005	0,000	0,000	0,055	0,000	0,000	0,006	0,000
Tanzania	0,000	0,000	0,000	0,064	0,000	0,180	0,000	0,000	0,000	0,000	0,000	0,019
S. Africa	0,000	0,021	0,000	0,000	0,000	0,036	0,024	0,000	0,000	0,000	0,000	0,006
Jordan	0,000	0,000	0,000	0,042	0,000	0,120	0,000	0,000	0,000	0,000	0,000	0,012
Iran	0,047	0,000	0,000	0,053	0,000	0,300	0,000	0,000	0,000	0,000	0,000	0,029

Table 3.18: Custom Cost of Manufacturers per Item / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2
Tunus	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2
Tanzania	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2
S. Africa	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2
Jordan	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2
Iran	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2

In terms of inventory holding cost we have cost details supplied from company which changes from manufacturer to manufacturer and item to item as it illustrated in Table 3.19 as weekly per unit. As industrial advisors mentioned this cost is simply calculated according to manufacturer and item bases by considering global interest rates, opportunity cost of tying up money and storage cost incurred in their warehouses.

Table 3.19: Weekly Inventory Holding Cost of Manufacturers per Unit Item / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,0048	0,0057	0,0048	0,0000	0,0014	0,0000	0,0000	0,0000	0,0123	0,0143	0,0123	0,0000
Tunus	0,0000	0,0000	0,0000	0,0057	0,0014	0,0000	0,0000	0,0014	0,0000	0,0000	0,0123	0,0000
Tanzania	0,0000	0,0000	0,0000	0,0057	0,0000	0,0014	0,0000	0,0000	0,0000	0,0000	0,0000	0,0123
S. Africa	0,0000	0,0057	0,0000	0,0000	0,0000	0,0014	0,0014	0,0000	0,0000	0,0000	0,0000	0,0123
Jordan	0,0000	0,0000	0,0000	0,0057	0,0000	0,0014	0,0000	0,0000	0,0000	0,0000	0,0000	0,0123
Iran	0,0048	0,0000	0,0000	0,0057	0,0000	0,0014	0,0000	0,0000	0,0000	0,0000	0,0000	0,0123

Out of these cost components it is necessary to illustrate how these costs are gathering together and total manufacturer cost has been calculated. The next section will elaborate on these calculations.

The final cost parameters are inventory holding and back order cost. Average inventory holding cost is given by the company as $0,032 as weekly for each unit whereas back order cost calculation is not given by the company itself. For this reason we have calculated average backorder cost for each item which is $0,5. Backorder cost is calculated by considering an urgent time for manufacturer when it requires an urgent order which should be delivered by a plain. For this reason, we have included average material cost, air shipment cost and extra production cost for suppliers which are also in the case of reality. As it can be observed backorder cost is quite higher than average inventory cost since facing with a stock out case is extremely bad case for this FMCG company.

3.3. Main Settings and Cost Formulations in Simulation Model for the Traditional Procurement Model

Starting point of our simulation model are demand entity creations blocks which are totally six blocks each represents a single manufacturer. These blocks are creating demand of manufacturer for each item of manufacturer with an exponential distribution with a mean 7 days. After these creations entities are entered into the assign block where their item and plant numbers are assigned. Please see Table 3.20 for assign variables used in simulation model. After a decision box they are again entered in different assign blocks and each item as an attribute has been attributed with a normally distributed demand and a specific standard deviation ratio. In this point each attribute has already had a unique item, plant and demand information. Thereafter the entities follow to decision box about whether on hand inventory is satisfying the demand or not. If the demand is satisfied, the entities are updating both physical inventory and inventory position variables and reach the decision module where the decision of creating a purchase order is taken. In other case, if the demand is not fully satisfied, existing inventory satisfies some proportion of the demand and again update the inventories by equating physical inventory value to zero. After this point entity again reaches to ordering decision box. Before coming to this ordering decision module there is another vital point in simulation which calculate fill rate of manufacturer i.e. the proportion of demand that is satisfied from existing physical inventory level of plant. Please see equation 3.4 for total demand calculation, equation 3.5 for satisfied demand calculations and equation 3.6 for fill rate calculation details. In order to calculate this fill rate total demand and total satisfied demand variables for each plant and item are kept as two dimension variables. All variables used for traditional supply chain structure of the company are illustrated in Table 3.21.

Table 3.20: Definition and calculation Details of Attributes

Attributes	Defition of Attributes	Calculation Details
Demand	Unique demand values which are assigned to single item, plant	Company weekly demand data is used with normal distribution and spesific standart deviation rate such as (%10, %30 and %60)
Numtruckload	Remainder of truckload value that is subtracted form integer truckload value	Truckload - AINT(truckload)
Orderqty	Purchase order quantities of plants that will be released to related supplier	Big S - inventory position(plant,item)
Truckload	Number of trucks that is required to transport materials from suppliers to plants	Orderqty / Trucksize(item)

<u>Equation 3.4</u>

Total demand (plant,item) = total demand (plant,item) + demand

<u>Equation 3.5</u>

Demand satisfied (plant,item) = demand satisfied (plant,item) + demand (if demand can be fully satisfied by physical inventory) or;

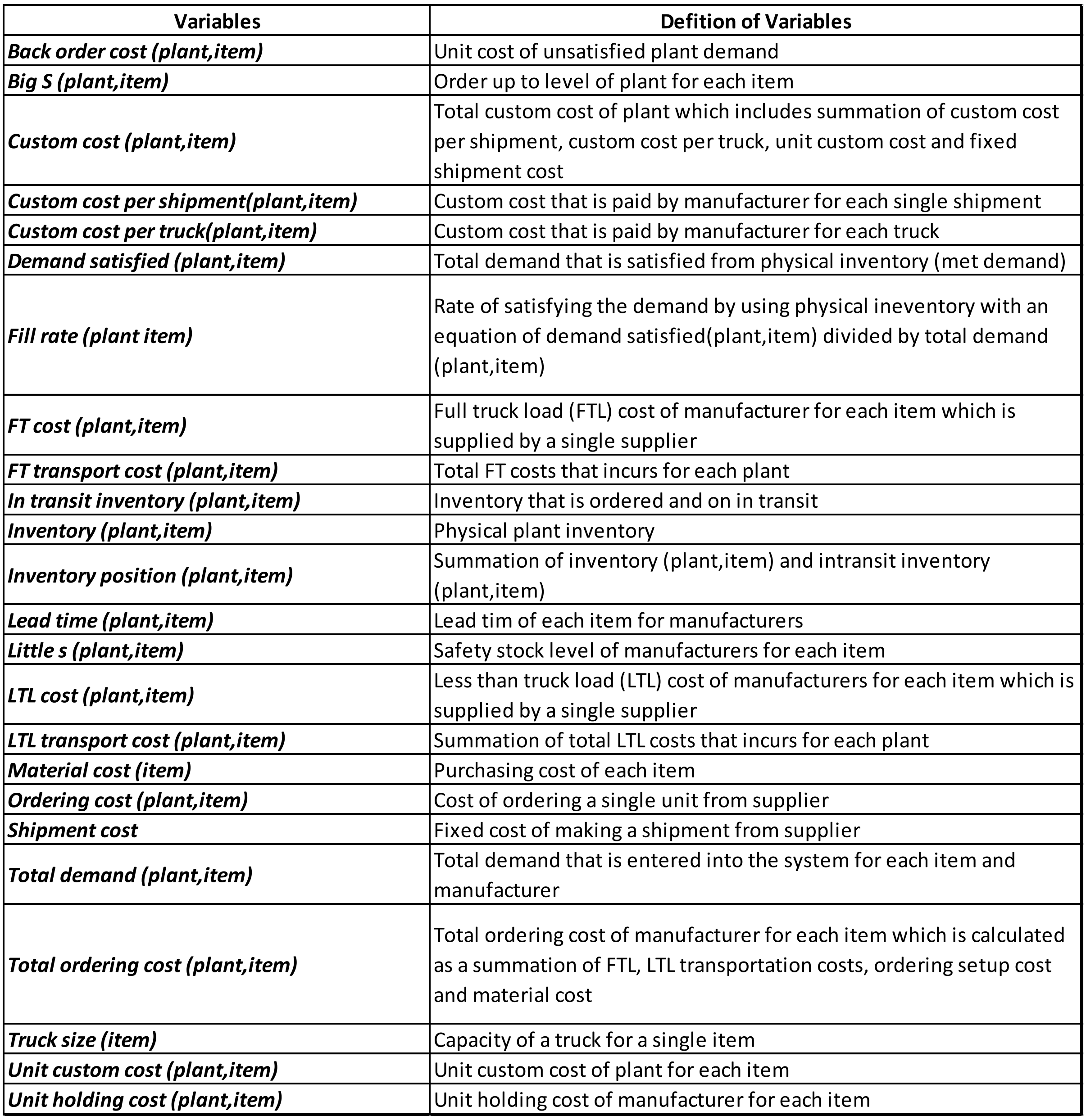
Demand satisfied (plant,item) = demand satisfied (plant,item) + inventory(plant,item) (if demand is partially satisfied or dissatisfied)

These two different calculations is separated between each other with a decision box about the satisfaction of demand. Thus, it is not possible for a single entity to update two different variables at the same time. In short, an entity can follow one of the equations according to inventory level.

Equation 3.6

Fill rate (plant,item) = demand satisfied (plant,item) / total demand (plant,item)

Table 3.21: Parameters Used in Simulation Model for Current Supply Chain Structure of the Company



Variables	Defition of Variables
Back order cost (plant,item)	Unit cost of unsatisfied plant demand
Big S (plant,item)	Order up to level of plant for each item
Custom cost (plant,item)	Total custom cost of plant which includes summation of custom cost per shipment, custom cost per truck, unit custom cost and fixed shipment cost
Custom cost per shipment(plant,item)	Custom cost that is paid by manufacturer for each single shipment
Custom cost per truck(plant,item)	Custom cost that is paid by manufacturer for each truck
Demand satisfied (plant,item)	Total demand that is satisfied from physical inventory (met demand)
Fill rate (plant item)	Rate of satisfying the demand by using physical ineventory with an equation of demand satisfied(plant,item) divided by total demand (plant,item)
FT cost (plant,item)	Full truck load (FTL) cost of manufacturer for each item which is supplied by a single supplier
FT transport cost (plant,item)	Total FT costs that incurs for each plant
In transit inventory (plant,item)	Inventory that is ordered and on in transit
Inventory (plant,item)	Physical plant inventory
Inventory position (plant,item)	Summation of inventory (plant,item) and intransit inventory (plant,item)
Lead time (plant,item)	Lead tim of each item for manufacturers
Little s (plant,item)	Safety stock level of manufacturers for each item
LTL cost (plant,item)	Less than truck load (LTL) cost of manufacturers for each item which is supplied by a single supplier
LTL transport cost (plant,item)	Summation of total LTL costs that incurs for each plant
Material cost (item)	Purchasing cost of each item
Ordering cost (plant,item)	Cost of ordering a single unit from supplier
Shipment cost	Fixed cost of making a shipment from supplier
Total demand (plant,item)	Total demand that is entered into the system for each item and manufacturer
Total ordering cost (plant,item)	Total ordering cost of manufacturer for each item which is calculated as a summation of FTL, LTL transportation costs, ordering setup cost and material cost
Truck size (item)	Capacity of a truck for a single item
Unit custom cost (plant,item)	Unit custom cost of plant for each item
Unit holding cost (plant,item)	Unit holding cost of manufacturer for each item

After these inventory updates and fill rate calculations, inventory controlling module takes place. This decision box checks whether below equation 3.7 is valid or not. If this equation is valid, there is no need for a purchase order so the entity leaves the system via a dispose block otherwise the entity goes to an assign block where order amount calculation is made. It is important that this inventory check is fulfilled with not only checking physical inventory level but also in transit inventory level. It might be useful to mention once again that inventory position is the summation of physical inventory and in transit inventory and necessity of an order is decided by reviewing this variable.

Equation 3.7

Inventory position (plant,item) > ***little_s (plant,item)***

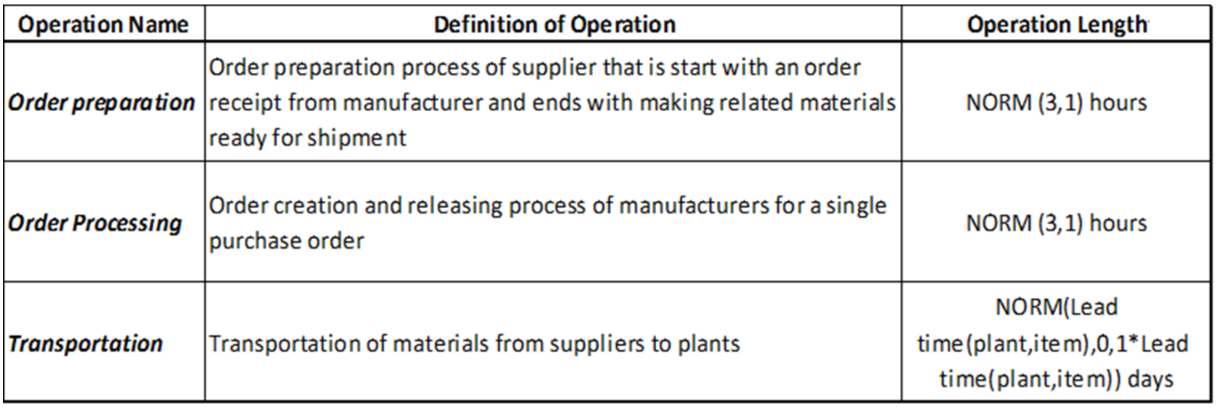
In terms of purchase order quantity calculation below simple equation 3.8 is being used. It is important to remind that as illustrated on Table 20 order quantity is an attribute that have information of demand value for a plant and a single item where as *big_S* and inventory position are two dimension variables as illustrated on Table 3.21.

Equation 3.8

Orderqty = big_S(plant,item) – inventory position(plant,item)

After order calculation process, order processing process starts as illustrated with other operations used in this simulation model with Table 3.22. This operation is exactly the same as in real life in terms of order quantity calculation by planning department and then order release by purchasing department.

Table 3.22: Main Operations Used in Simulation Model for Current Supply Chain Structure of the Company



Operation Name	Definition of Operation	Operation Length
Order preparation	Order preparation process of supplier that is start with an order receipt from manufacturer and ends with making related materials ready for shipment	NORM (3,1) hours
Order Processing	Order creation and releasing process of manufacturers for a single purchase order	NORM (3,1) hours
Transportation	Transportation of materials from suppliers to plants	NORM(Lead time(plant,item),0,1*Lead time(plant,item)) days

When supplier received the official order from manufacturer's purchasing department order preparation time starts which represent dedication of mentioned quantity from supplier stock to the manufacturer. This process takes a short time since it is just dedication of some portion of inventory and complete booking. We assume that supplier has always enough capacity to satisfy manufacturer's demand. Thus, there is no probability of being stock out on the supplier side. In meantime manufacturer's in transit inventory and inventory position are updated due to new order quantity that is released by supplier as shown in equation 3.9 and 3.10.

Equation 3.9

Intransit inventory(plant,item) = intransit inventory(plant,item) + orderqty

Equation 3.10

Inventory position(plant,item) = inventory(plant,item) + intransit inventory(plant,item)

After these updates are completed, important calculations follow the system such as truckload and remainder of truck load value that is subtracted form integer truckload value are calculated in order to be able to calculate transportation cost in an easier way. Please see below truckload and remainder of truck load calculation equations respectively with equation 3.11 and 3.12 in our simulation model.. Please note that truckload and *numtruckload* values are attributes as they are shown in Table 3.20. The reason of calculation *numtruckload* value is to calculate LTL cost easily. Since our LTL costs represent a full truck's LTL cost it is convenient to use remainder of truckload which is *numtruckload* attribute in our simulation model.

Equation 3.11

Truckload = orderqty / trucksize(item)

Equation 3.12

Numtruckload = truckload - AINT(truckload)

Another vital point in real life in terms of transportation cost is that if a truck or container is less fully than 72% percent of the truck it is more economical to use partial (LTL) transportation option rather than FTL due to transportation and custom related costs. On the other hand, if the volume or weight of materials are covering the volume of more than 72% of full container or truck than it is more convenient to prefer a full truck load (FTL) instead of partial truck (LTL) alternative. Thus, in real life the company prefers to convert less than truck loads to full truck load if the fullness is above 72% in order to save in transportation and custom costs. For this reason we have replicate the real life case in our model as it is by using a decision box that has equation 3.12 and using different calculation types as illustrated in equation 3.13 and 3.14. If equation 3.13 is valid than the entity follow the equation 3.14 and calculate LTL transportation cost otherwise equation 3.15 is used for FTL transportation cost calculation. In the meantime, while computing these cost FTL and LTL cost variables that are illustrated on Table 3.12 and 3.13 are used.

Equation 3.13

Numtruckload < 0.72

Equation 3.14

LTL transportcost (plant,item) = LTL transportcost (plant,item) + (AINT(truckload)* FT cost (plant,item))+ (numtruckload * LTL cost (plant,item))

Equation 3.15

FTL transportcost (plant,item) = FTL transportcost (plant,item) + (AINT(truckload)+1) * FT cost (plant,item)

After calculation of transportation related costs the model is followed by the calculation of plant's total custom cost. Total custom cost is composed of various costs as it is illustrated with below equation 3.16. Please see Table 15, Table 16, Table 17 and Table 18 for the components of total custom cost.

Equation 3.16

Customcost(plant,item) = customcost(plant,item) + shipmentcost + customcost per shipment(plant,item) + (custom cost per truck(plant,item) * AINT(truckload)) + (unit custom cost * orderqty)

Similarly total ordering cost has been calculated by using below equation 3.17. Please see Table 12, Table 13 and Table 14 for the components of total ordering cost.

Equation 3.17

Total ordering cost(plant,item) = total ordering cost(plant,item) +LTL transport cost(plant,item) + FT transportcost(plant,item) + ordering cost(plant,item) + (material cost(item) * orderqty)

As a last few step transportation process take place with a 10% standard deviation which is also so similar to real life case and written in transportation process module as a value of *NORM (leadtime(plant,item), 0.1*leadtime(plant,item)).* Lead times differ from each other for each material and manufacturer since they are supplied by various suppliers which have geographically different lead times to manufacturers. Please see table 3.4 for related lead time values for each manufacturer and item. Finally, after entity waits until transportation process ends it enters in order update blocks where physical inventory, in transit inventory and inventory position are updated. These updates are completed with the following Equation 3.18, 3.19 and 3.20 respectively. As a last step, entity leaves the system via a dispose block.

Equation 3.18

Inventory(plant,item) = inventory(plant,item) + orderqty

Equation 3.19

Intransit inventory(plant,item) = Intransit inventory(plant,item) – orderqty

Equation 3.20

Inventory position(plant,item) = inventory(plant,item) + intransit inventory(plant,item)

Before running the simulation model initial inventory levels of manufacturers are defines as up to inventory level which means beginning inventory levels of manufacturers are equal to *big S* values as shown with equation 3.21.

Equation 3.21

inventory(plant,item) = big_S(plant,item) = inventory position(plant,item)

The main components of the simulation model for the current structure of the company are representing with a diagram below Figure 3.2. After completing the setting of the model, inputs are loaded into the simulation model and they are run. The outputs of the simulation model for the current business structure are illustrated in chapter 5 where all scenarios are gathered and commented together.

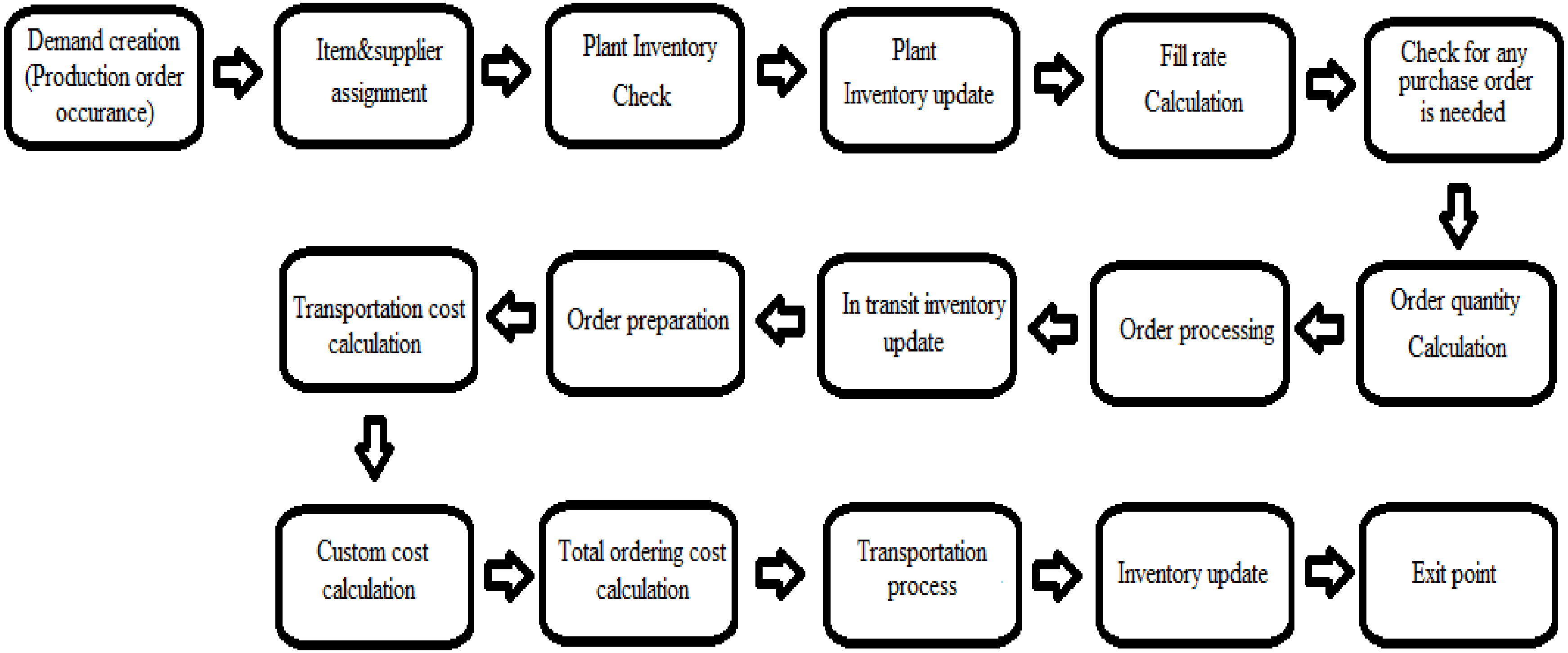


Figure 3.2: Main setting in simulation model for current procurement structure

CHAPTER IV

ALTERNATE SUPPLY CHAIN STRUCTURE FOR THE COMPANY

Throughout this chapter alternate business structure we developed has been discussed. Since there are two different supply chain designs where one and two hubs introduced, all structure has been analyzed in two main components which is one hub and two hubs included structures. Moreover, these new structures have been reviewed with its new cost components and the calculation details of them. Finally, the main seating in simulation models for this alternate supply chain design has been illustrated with all detailed model components.

4.1 Alternate Business Procurement Model

As an alternative to the current supply chain structure of the company it might be possible to use supply hub(s) that will be used as a consolidation point that is located in a strategic location. What we mean by supply hubs is widely known as a consolidation point or warehouse that will supply the materials from suppliers in bigger batches and ship them in smaller batches to the regional manufacturers when they need. These hubs will consolidate the requirements of the manufacturers and ship different materials ordered with a single shipment. We thought that if these hubs or hub is located in a proper place there might be some opportunities in terms of transportation cost saving and demand fill rate increase.

The system in simulation model will be composed of three levels which are suppliers, supply hubs and manufacturers. Thus, it can be said that this system will have two echelons when it compares to current single echelon structure. Suppliers will be able to use same hubs commonly for their specific materials. In this structure, the material flow will be like figure 4.1 below. As it can be observed from this figure, suppliers will assign to a single supply hub and they will only ship their inventories to assigned supply hub. Through the inventory flow between supply hubs and manufactures, manufacturers will be able to receive materials from both supply hubs. However, in this new structure supply hubs will have unique materials which mean same material cannot be located in both supply hubs.

In terms of safety stock level of supply hubs and suppliers there are different policies in this structure. For example, supply hubs are holding their safety stock levels according to the lead time demand of manufacturers. Through the material flow of supply hubs and manufacturers, inventory replenishment is fulfilled with an *s,S* inventory. On the other hand, since in this new structure the supply point is supply hubs for manufacturers instead of suppliers, we assume that suppliers produce its goods and sent directly to supply hubs according to an *s,S* policy again. When orders amounts are determined by supply hubs according to an *s,S* policy, related orders are shipped by suppliers. In this structure, we assume that suppliers are holding one week demand of supply hubs as a ROP.

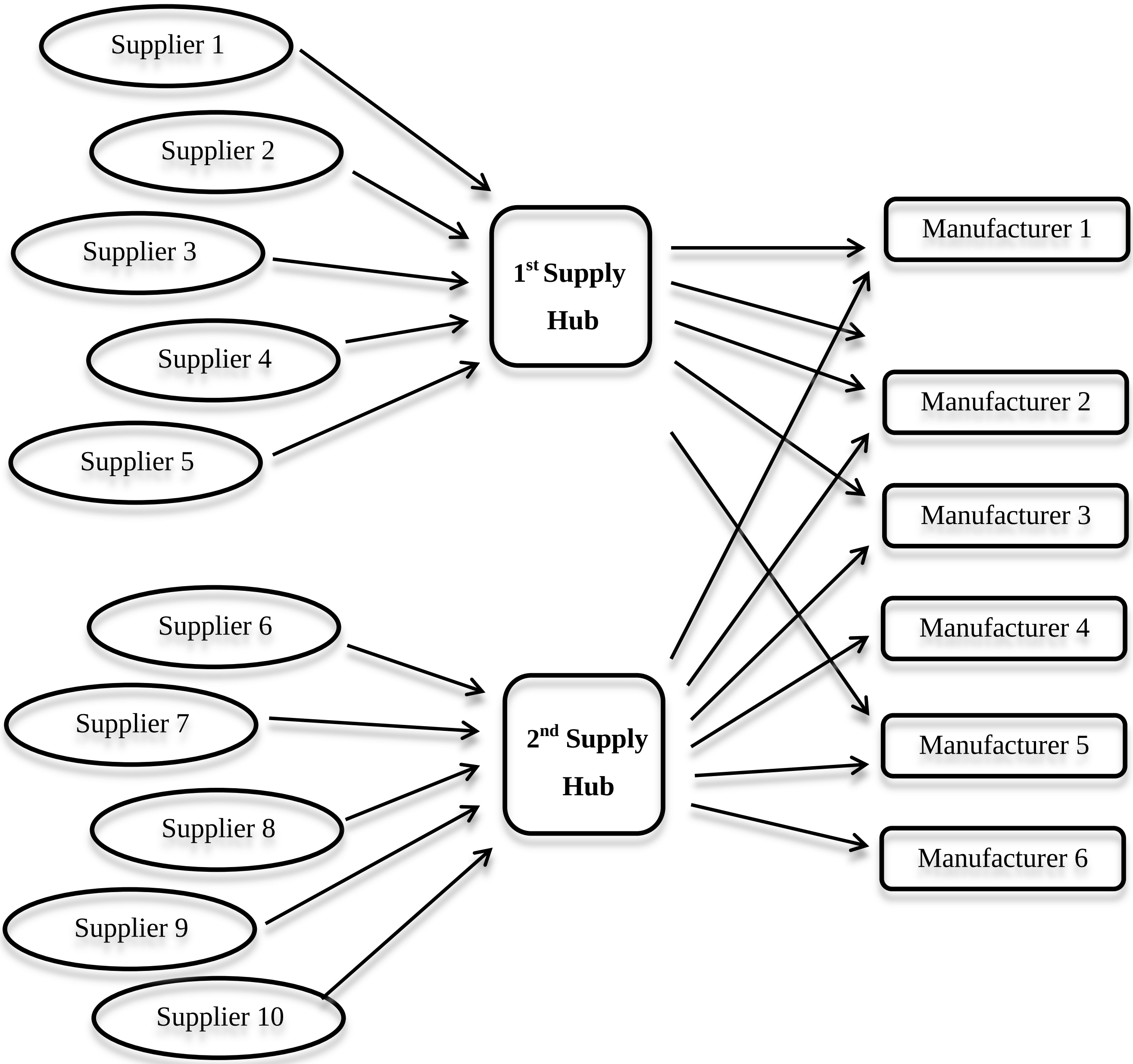


Figure 4.1: An Example for Inbound Inventory Flow in Alternate Model

We assume that perfect inventory information on the supply hubs is assumed to be available for each supplier. The part of the system from the supplier until the shipments from the supply hubs to manufacturers is assumed to be controlled by the suppliers.

This viewpoint indicates that supply hubs play the role of a stocking location for the suppliers, act as a transition warehouse. The safety stock levels of hubs are determined by the supplier. The whole process under consideration is triggered by the forecast information of the regional manufacturers received by the suppliers. The process involves replenishments from suppliers to supply hubs and shipments from the supply hubs to manufacturers according to an *s,S* inventory management policy.

In this structure we assume that suppliers have infinite capacity and supply hubs can replenish their inventory when their inventory level decrease to re order point (*s*) level or under this level as it is the case in *s,S* inventory management policy. Similar to current business procurement structure defined in chapter 3, we covered all the cost of inventory flow between suppliers and supply hubs such as transportation cost, custom costs, ordering costs and inventory holding cost of supply hubs. By including all cost details that is included in traditional procurement model for the inventory flow between suppliers and supply hubs we would be able to make comparison and analysis in terms of the total system cost between without hub and hub included scenarios.

As in the previous chapter in traditional structure supplier capacity is assumed to be infinite and it can make shipments when hubs require. Moreover, another common point in these two systems is that supply production costs or production related other costs are not included in simulation models. Although suppliers decide on the quantity, frequency of shipments from their site to the associated supply hub as a setup, we have calculated safety stock and up to inventory levels of supply hubs for different demand rate scenarios (low, medium and high demand), service level type (company policy, 98% and 90% service levels) and standard deviation rates alternatives (10%, 30%, and 60%) as it in the case in traditional structure about manufacturer side. In addition to these scenarios there is another in this alternate system which is about the number of hubs included as single hub included structure and two hubs included structure.

In alternate supply chain design materials are stored by the supply hub and consolidated for combined distribution to the manufacturers, based on the orders. In order to enable this consolidation we create a consolidation system in our simulation model. This consolidation part of simulation receives orders from manufacturers and after receiving these orders waits until a specified period, and if another order from the same manufacturer is received within this period then the orders are consolidated into a single shipment and shipped with a single truck or container. We assume that this consolidation system is enabling to get a benefit for manufacturer in terms of transportation and custom cost.

In addition to this consolidation logic another smart system is built for the shipments from suppliers to supply hubs. This system simply uses the advantage of economies of scale logic. This system can be regarded as a round up shipment policy which round up order quantities of supply hubs to a truck size if the order quantity fills the truck's capacity more than 72% percent. If the order quantity is less than this ratio, then the truck is released by supplier side with LTL shipment which is 20% more expensive than the FTL cost. The advantage of using such a round up shipment quantity policy is quite obvious that is saving from transportation and custom related costs. A similar system is also valid for the traditional model but in that model there is no round up policy. In that part the issue is related with just calculation of transportation cost. In that policy if the truckload is more than 72% of the truck size the transportation fulfilled by a FTL shipment and so FTL cost is calculated without any shipment quantity round up.

Supply chain network design idea comes from a logic that may be necessary for the company's supply chain structure. This logic is firstly established by Göçer (2010). The materials that are covered both in the traditional and in the alternative models are the common, high volume, higher priced ones which have long lead times. We assume that this setting will be benefiting in terms of economies of scale. Besides, high volume-high price products are more important both in terms of cost optimization and in term of cash flow management.

Furthermore, the alternate supply chain infrastructure is expected to provide more flexibility and much lower stock out risk due to lead time between manufacturers and supply hubs. That is enhanced by using closer supply hubs to substitute further away many manufacturers; hence reducing lead times. There is also a postponement of the decision on the ownerships of the products with the use of supply hubs. As the allocation of products to the manufacturer' demand is postponed, uncertainty situations are also covered in a smooth way. Besides, for unexpected situations, keeping aggregate inventory at the supply hub's site provides risk pooling as well. All may improve the demand fill rate levels through the whole supply chain.

On the other side, this supply chain structure may also be expected to bring some challenges to all parties involved; however, if the structure is carefully established and managed, it can also provide significant benefits. Therefore, it becomes more important here to correctly identify, define and determine the responsibilities of each party. For instance, the number of less than truck load shipments may be reduced or the postponement on the invoicing period may be a significant benefit for the manufacturer in terms of cash flow management as the financial ownership of the inventory will be transferred to the manufacturers at a later step; however this will surely increase suppliers' costs.

In terms of the model setting and data used in this alternative model is nearly the same as the previous traditional procurement model. Because, the same data set is used for this model in terms of the manufacturer part. All cost parameters of manufacturer part are exactly same as with the previous model and the model is constructed with the same inventory management philosophy. For example, this alternate model is including the same data set as in previous traditional model settings' Table 3.1, Table 3.2 and Table 3.3 which represents item-manufacturer details, purchasing cost of items and truck size respectively. Similarly, as in the previous model this model uses *s,S* inventory management philosophy and when a stock level of both manufacturer and supplier decreases under *s* (ROP), the system creates an order for the supplying party by considering up to inventory level. For this reason the additional part of inventory management in this alternate model are the inventory flow between suppliers and hubs and secondly the flow between supply hubs to manufacturer. For clarification please see equation 3.1 which illustrates inventory management components of manufacturers. These components are exactly the same in this alternative model also. However, by considering these components manufacturers send their order to supply hubs which is new in this system. For this reason, manufacturers' Q* and *S* values are re-calculated with the revised lead times between supply hubs and manufacturers as illustrated with Table 4.1. Since lead time between manufacturers and suppliers and between manufacturers and supply hubs are completely different, lead time demands of manufacturers change significantly. For this reason all *s*, *Q** and *S* values are updated. Please see Table 4.2 for updated manufacturer *s* (ROP) values, Table 4.3 for updated *Q**(optimum order quantity levels) and Table 4.4 for updated *S* (order up to) values.

Table 4.1: Transportation Lead Time between Hub in Turkey and Manufacturers in terms of Days

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	1	1	1	0	1	0	0	0	1	1	1	0
Tunus	0	0	0	7	7	0	0	7	0	0	7	0
Tanzania	0	0	0	25	0	25	0	0	0	0	0	25
S. Africa	0	28	0	0	0	28	28	0	0	0	0	28
Jordan	0	0	0	21	0	21	0	0	0	0	0	21
Iran	14	0	0	14	0	14	0	0	0	0	0	14

Table 4.2: ROP (Little_s) Values of Manufacturers under Company Policy, Medium Demand and 10% Standard Deviation in Alternate Model

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	12.463	6.228	1.244	0	249.281	0	0	0	1.866	622	622	0
Tunus	0	0	0	2.488	2.488	0	0	28.667	0	0	369	0
Tanzania	0	0	0	10.437	0	130.558	0	0	0	0	0	1.738
S. Africa	0	3.672	0	0	0	27.581	18.390	0	0	0	0	545
Jordan	0	0	0	6.567	0	82.112	0	0	0	0	0	982
Iran	7.220	0	0	7.220	0	180.602	0	0	0	0	0	2.163

Table 4.3: Optimum Ordering Amount (Q* Values) of Manufacturers in Alternate Model

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	12.752	8.273	4.029	0	107.031	0	0	0	3.095	1.653	1.782	0
Tunus	0	0	0	5.259	10.531	0	0	35.822	0	0	1.400	0
Tanzania	0	0	0	9.136	0	64.610	0	0	0	0	0	2.590
S. Africa	0	5.357	0	0	0	29.329	24.407	0	0	0	0	1.377
Jordan	0	0	0	7.479	0	52.771	0	0	0	0	0	1.946
Iran	8.997	0	0	8.256	0	83.383	0	0	0	0	0	3.089

Table 4.4: Order up to Level (Big_S) Values of Manufacturers under Company Policy, Medium Demand and 10% Standard Deviation in Alternate Model

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	25.215	14.501	5.273	0	356.312	0	0	0	4.961	2.275	2.404	0
Tunus	0	0	0	7.747	13.019	0	0	64.489	0	0	1.769	0
Tanzania	0	0	0	19.573	0	195.168	0	0	0	0	0	4.328
S. Africa	0	9.029	0	0	0	56.910	42.797	0	0	0	0	1.922
Jordan	0	0	0	14.046	0	134.883	0	0	0	0	0	2.928
Iran	16.217	0	0	15.476	0	263.985	0	0	0	0	0	5.252

In the former traditional model these manufacturer orders are directly being sent to supplier instead. In addition to existing manufacturers' inventory management components (*little_s* and *big_S*) as illustrated with equation 3.1 in previous section we have additional inventory management components for supply hubs in this alternate model as illustrated by Equation 4.1 below.

Equation 4.1

Inventory position of hub(hubassign,item) = inventory of hub(hubassign,item) + in transit inventory of hub(hubassign,item)

What is new in this system is that we hold *hubassign* variable which represent hub's simulation model code as *hub 1* or *hub 2* since we have two alternatives in terms of the number of hubs as 1 hub included and 2 hubs included scenarios. Please see Table 4.9 for an example of this item-hub assignment in two hubs included scenario. In addition to previous traditional model we have *hub little_s* and *hub big_s* variables for hub party. It is meaningful to share below variables that are held through the simulation model in order to manage inventory of hub side.

inventory of hub(hubassign,item) Physical inventory level of hub for a specific item.

in transit inventory of hub(hubassign,item) Inventory level of hub which is in transit.

Similar to manufacturer party supply hubs have ROP and up to inventory levels as illustrated below with hub little_*s* and hub big_*s* variables.

hub little_s(hubassign,item) Re order level kept at supply hub for a single item

hub big_S(hubassign,item) Order up to level of supply hub for a single item (Maximum amount of material that is required to be held by supply hubs)

In terms of hub little_s and hub big_s values there is a fixed policy for the calculation of hubs' *s* and *S*. Supply hubs' s values are calculated by using 98% service level logic by using new lead times between suppliers and supply hubs. These lead times are calculated with item and manufacturer as a model input illustrated in Table 4.5 as daily basis. Table 4.5 illustrates the lead times of Turkey hub to suppliers and there is another table which changes for the item 6 and item 12 with the involvement of second Dubai hub for two hub included scenario.

Table 4.5: Transportation Lead Time between Supply Hub (Turkey) and Suppliers under One Hub Included Scenario / Days

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	14	28	42	14	1	28	28	35	14	21	7	14

Different than the traditional model, the calculation of hubs' *s* and *S* values does not change for different service levels. On the other hand, these values are updated when demand ratio alternatives (low, medium and high demands) and standard deviation alternatives (10%, 30% and 60%) changes. Please see an example of Turkey hub's *s* values in Table 4.6 for one hub included structure with 10% standard deviation and medium demand alternative, the same logic is also followed with the introduction of second Dubai hub as a two hubs included scenario.

Table 4.6: ROP (little_s) Values of Hubs for One Hub Included Structure under Medium Demand and 10% Standard Deviation Scenario / Days

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	6.607	3.895	1.248	10.722	46.846	260.123	8.484	24.152	659	322	287	1.982

Similar to former traditional model setting order up to inventory levels of hubs (*hub big_S* values) are calculated with the same logic of manufacturers side as indicated with equation 4.2 below. In this calculation Q* values of hubs are calculated by summing manufacturers' Q* values on item basis. Thus, it is clear that hub Q* values have higher values than manufacturers Q* values. Please see Table 4.7 for these hub Q* values for single hub included structure. The same logic is also followed by two hubs included structure.

Equation 4.2

hub big_S(hubassign,item) = hub little_s(hubassign,item) + Q* (hubassign,item)

Table 4.7 shows optimum order quantities (*Q**) of hubs for single hub included supply chain design for the scenario of 10% standard deviation and medium demand while Table 4.8 illustrates order up to inventory (*S*) levels for the same structure and alternative. As it can be understood that hub *Q**, *s* and *S* values are re-calculated for different scenarios on service standard deviations and demand rates and also supply chain structure scenario as one and two hubs included systems.

Table 4.7: Optimum Order Quantity (Q*) Values of Hubs for One Hub Included Structure under Medium Demand and 10% Standard Deviation Scenario / Unit

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	21.749	13.630	4.029	30.130	117.562	230.093	24.407	35.822	3.095	1.653	3.182	9.002

Table 4.8: Order Up to Inventory (hub big_S) Values of Hubs for One Hub Included Structure under Medium Demand and 10% Standard Deviation Scenario / Unit

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	28.356	17.525	5.277	40.852	164.408	490.216	32.891	59.974	3.754	1.975	3.469	10.984

While determining supply order quantities of hubs the same logic as tradition model is followed. Calculations of these values are followed by the equation 4.3 as below.

Equation 4.3

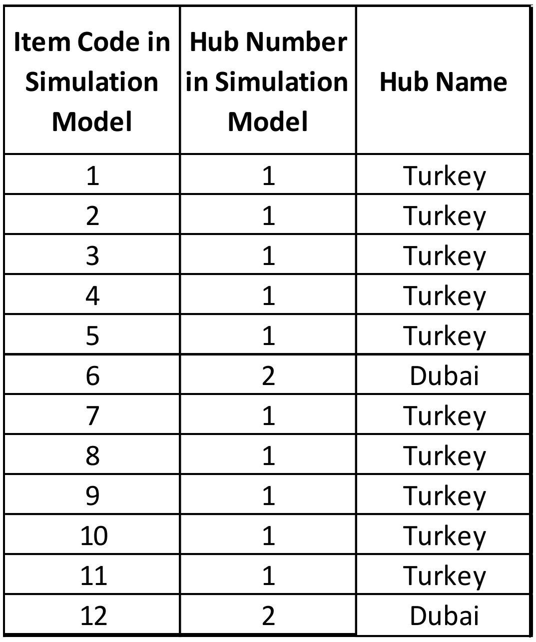
hub orderqty = hub big_S(hubassign,item) – inventory position of hub (hubassign,item)

As an alternative to traditional procurement model we have established two different supply chain structures which are 1 hub included and 2 hubs included structures. The logic of these two alternatives comes from Göçer (2010) establishes different supply chain alternatives as 1, 2, 3, 4, 5 and 6 supply hub included structures. Out of these different structures their mathematical model was proposing one hub and two hubs included structures where the total cost is the same as traditional structure where there is no hub. Thus, we prefer to include only these two alternatives which are proved before as the best ones out of other alternatives in terms of total logistics cost.

The locations of these hubs in this study are also the same as their study. The first alternative in their study was including a single hub included system where this hub is located in Turkey. In the second alternative they use two hubs which are located in Turkey and Dubai. Moreover, they had also made an analysis about the items-hub assignment in terms of which items should be located to which hub. According to their setting in two hubs included alternative the best item-hub assignment that minimizes total logistics cost is illustrated in below Table 4.9. As it is obvious in one hub included structure all items are assigned to single hub i.e. Turkey since there is no other chance. This one hub included system’s item hub assignment is illustrated with Table 4.10.

As it is observed from these tables in one hub included alternative, Turkey is used for handling all 12 different items while in two hubs included structure item 6 and item 12 are assigned to Dubai whereas others are assigned to hub that is located in Turkey.

Table 4.9: Item-Hub Assignment in Alternative Model where Two Hubs Are Used



Item Code in Simulation Model	Hub Number in Simulation Model	Hub Name
1	1	Turkey
2	1	Turkey
3	1	Turkey
4	1	Turkey
5	1	Turkey
6	2	Dubai
7	1	Turkey
8	1	Turkey
9	1	Turkey
10	1	Turkey
11	1	Turkey
12	2	Dubai

Table 4.10: Item-Hub Assignment in Alternative Model where Single Hub is Used

Item Code in Simulation Model	Hub Number in Simulation Model	Hub Name
1	1	Turkey
2	1	Turkey
3	1	Turkey
4	1	Turkey
5	1	Turkey
6	1	Turkey
7	1	Turkey
8	1	Turkey
9	1	Turkey
10	1	Turkey
11	1	Turkey
12	1	Turkey

4.2. Cost Components of the Manufacturers in Alternate Structures

In the alternate supply chain structure, simulation model is constructed with a quite similar logic to the tradition procurement model. The setting is nearly the same as in traditional procurement simulation model. The main change is about inventory flow which is altered from single echelon to two echelon system. Similar to former traditional simulation model, order amounts and times are determined by manufacturer itself by reviewing inventory position and demand forecasts but these orders are sent to supply hubs instead of suppliers. We assume that the agreement between the supply hubs and manufacturers is again based upon the ex-works sales of the products. Thus, transportation cost from the supply hubs to the manufacturers is incurred by the manufacturers themselves. Besides, invoices for orders are issued by the supply hubs to the manufacturer as soon as the orders are shipped from the supplier‘s facilities. This then implies that the associated costs during the lead time are incurred by the manufacturer again. However, in this structure these lead time periods will be less than the tradition structure because supply hubs will generally be closer to manufacturer than suppliers. Through this two echelon ordering cycle various cost are generated at the manufacturer‘s side such as transportation cost, inventory holding cost, customs and agencies cost, and ordering cost for each unit and time similar to traditional model.

Similar to traditional procurement structure there are two types of transportation cost in the alternate models which are full truck load (FTL) cost and less than truck load (LTL) costs. LTL costs are 20% more expensive than the FTL costs as it is in the case of traditional structure. Since the lead times between suppliers to manufacturers and supply hubs to manufacturers are completely different in alternate model, all FTL and LTL costs are re-calculated. Moreover, since there are two alternate supply chain structures, model inputs of these alternatives are re-calculated and changed accordingly. In addition to transportation cost, custom clearance related costs are also revised for this alternate model.

On the other hand, there are also other cost components which are exactly the same as in traditional procurement structure such as inventory holding, ordering, back order, unit material costs, ordering cost, fixed cost of ordering and fixed shipment cost. These cost components are exactly the same as in tradition structure without any change. Similarly, calculation of total ordering, total custom, total backorder and total inventory holding costs are exactly the same as in traditional model.

In order to simply illustration, we have divide the cost component section into two as single hub included and two hub included structures.

4.2.1 Cost Components of Manufacturers in Single Hub Alternate Structure

Transportation and custom related costs are re-calculated for both alternate structures. These costs are changed as an input of alternate model. In this section, all cost details of hubs will be reviewed under single hub included scenario where supply hub Turkey takes place only. Table 4.11 illustrates FTL cost that incur for the transit between supply hub and manufacturers while Table 4.12 demonstrates LTL cost of the same echelon which are 20% more expensive than the FTL costs.

Table 4.11: FTL Cost of Manufacturers in One Hub Included Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	100	100	100	100	100	100	100	100	100	100	100	100
Tunus	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Tanzania	3.150	3.150	3.150	3.150	3.150	3.150	3.150	3.150	3.150	3.150	3.150	3.150
S. Africa	3.310	3.310	3.310	3.310	3.310	3.310	3.310	3.310	3.310	3.310	3.310	3.310
Jordan	1.966	1.966	1.966	1.966	1.966	1.966	1.966	1.966	1.966	1.966	1.966	1.966
Iran	1.300	1.300	1.300	1.300	1.300	1.300	1.300	1.300	1.300	1.300	1.300	1.300

Table 4.12: LTL Cost of Manufacturers in One Hub Included Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	120	120	120	120	120	120	120	120	120	120	120	120
Tunus	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.400
Tanzania	3.780	3.780	3.780	3.780	3.780	3.780	3.780	3.780	3.780	3.780	3.780	3.780
S. Africa	3.972	3.972	3.972	3.972	3.972	3.972	3.972	3.972	3.972	3.972	3.972	3.972
Jordan	2.359	2.359	2.359	2.359	2.359	2.359	2.359	2.359	2.359	2.359	2.359	2.359
Iran	1.560	1.560	1.560	1.560	1.560	1.560	1.560	1.560	1.560	1.560	1.560	1.560

Similar to transportation costs custom related costs are also re-calculated with the introduction of one hub included structure. Please see Table 4.13 for custom cost per shipment, Table 4.14 for custom cost per truck and Table 4.15 for custom cost per unit in one hub included structure.

Table 4.13: Custom Cost of Manufacturers in One Hub Included Structure per Shipment / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Tunus	0,000	0,000	0,000	0,007	0,002	0,000	0,000	0,018	0,000	0,000	0,002	0,000
Tanzania	0,000	0,000	0,000	0,021	0,000	0,060	0,000	0,000	0,000	0,000	0,000	0,006
S. Africa	0,000	0,007	0,000	0,000	0,000	0,012	0,008	0,000	0,000	0,000	0,000	0,002
Jordan	0,000	0,000	0,000	0,014	0,000	0,040	0,000	0,000	0,000	0,000	0,000	0,004
Iran	0,016	0,000	0,000	0,018	0,000	0,100	0,000	0,000	0,000	0,000	0,000	0,010

Table 4.14: Custom Cost of Manufacturers in One Hub Included Structure per Truck / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Tunus	0,000	0,000	0,000	0,021	0,005	0,000	0,000	0,055	0,000	0,000	0,006	0,000
Tanzania	0,000	0,000	0,000	0,064	0,000	0,180	0,000	0,000	0,000	0,000	0,000	0,019
S. Africa	0,000	0,021	0,000	0,000	0,000	0,036	0,024	0,000	0,000	0,000	0,000	0,006
Jordan	0,000	0,000	0,000	0,042	0,000	0,120	0,000	0,000	0,000	0,000	0,000	0,012
Iran	0,047	0,000	0,000	0,053	0,000	0,300	0,000	0,000	0,000	0,000	0,000	0,029

Table 4.15: Custom Cost of Manufacturers in One Hub Included Structure per Item / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Tunus	1,2	0,0	0,0	1,2	1,2	0,0	0,0	1,2	0,0	0,0	1,2	0,0
Tanzania	0,0	0,0	0,0	1,2	0,0	1,2	0,0	0,0	0,0	0,0	0,0	1,2
S. Africa	0,0	1,2	0,0	0,0	0,0	1,2	1,2	0,0	0,0	0,0	0,0	1,2
Jordan	0,0	0,0	0,0	1,2	0,0	1,2	0,0	0,0	0,0	0,0	0,0	1,2
Iran	1,2	0,0	0,0	1,2	0,0	1,2	0,0	0,0	0,0	0,0	0,0	1,2

In terms of the cost components that are updated for one hub included scenario one of the main points is that since Turkey as a hub is valid, the manufacturer in Turkey does not pay any custom related costs. Similarly, transportation cost decreases significantly for Turkey manufacturer. In addition to these obvious alterations other manufacturers' transportation cost are also changed. On the other hand, custom related costs are not changed for the manufacturers except form Turkey manufacturer. Since, these manufacturers will use Turkey as a supply hub they will proceed paying custom related cost as usual.

4.2.2 Cost Components of Manufacturers in Two Hub Included Alternate Structure

Similar to one hub included system transportation and custom related cost components of manufacturers are updated when Dubai as a second hub is introduced. Table 4.16 illustrates updated FTL cost while Table 4.17 shows updated LTL cost in two hubs included scenario.

Table 4.16: FTL Cost of Manufacturers in Two Hubs Included Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	100	100	100	100	100	2.601	100	100	100	100	100	2.601
Tunus	2.000	2.000	2.000	2.000	2.000	3.320	2.000	2.000	2.000	2.000	2.000	3.320
Tanzania	3.150	3.150	3.150	3.150	3.150	2.910	3.150	3.150	3.150	3.150	3.150	2.910
S. Africa	3.310	3.310	3.310	3.310	3.310	2.296	3.310	3.310	3.310	3.310	3.310	2.296
Jordan	1.966	1.966	1.966	1.966	1.966	2.455	1.966	1.966	1.966	1.966	1.966	2.455
Iran	1.300	1.300	1.300	1.300	1.300	475	1.300	1.300	1.300	1.300	1.300	475

Table 4.17: LTL Cost of Manufacturers in Two Hubs Included Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	120	120	120	120	120	3.121	120	120	120	120	120	3.121
Tunus	2.400	2.400	2.400	2.400	2.400	3.984	2.400	2.400	2.400	2.400	2.400	3.984
Tanzania	3.780	3.780	3.780	3.780	3.780	3.492	3.780	3.780	3.780	3.780	3.780	3.492
S. Africa	3.972	3.972	3.972	3.972	3.972	2.755	3.972	3.972	3.972	3.972	3.972	2.755
Jordan	2.359	2.359	2.359	2.359	2.359	2.946	2.359	2.359	2.359	2.359	2.359	2.946
Iran	1.560	1.560	1.560	1.560	1.560	570	1.560	1.560	1.560	1.560	1.560	570

When these tables are compared with the previous FTL and LTL cost tables in single hub included system, it can be observed that the cost of 6th and 12th items which are included in Dubai (hub code 2) are changed while other items remain same since remaining items are supplied from the same hub i.e. Turkey hub (hub code 1).

Similar to transportation costs, custom related costs are also updated for two hubs included system. Please see Table 4.18 for updated custom cost per shipment, Table 4.19 for updated custom cost per truck and Table 4.20 for updated custom cost per unit.

Table 4.18: Custom Cost of Manufacturers in Two Hubs Included Structure per Shipment / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Tunus	0,000	0,000	0,000	0,007	0,002	0,000	0,000	0,018	0,000	0,000	0,002	0,000
Tanzania	0,000	0,000	0,000	0,021	0,000	0,060	0,000	0,000	0,000	0,000	0,000	0,006
S. Africa	0,000	0,007	0,000	0,000	0,000	0,012	0,008	0,000	0,000	0,000	0,000	0,002
Jordan	0,000	0,000	0,000	0,014	0,000	0,040	0,000	0,000	0,000	0,000	0,000	0,004
Iran	0,016	0,000	0,000	0,018	0,000	0,100	0,000	0,000	0,000	0,000	0,000	0,010

Table 4.19: Custom Cost of Manufacturers in Two Hubs Included Structure per Truck / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Tunus	0,000	0,000	0,000	0,021	0,005	0,000	0,000	0,055	0,000	0,000	0,006	0,000
Tanzania	0,000	0,000	0,000	0,064	0,000	0,180	0,000	0,000	0,000	0,000	0,000	0,019
S. Africa	0,000	0,021	0,000	0,000	0,000	0,036	0,024	0,000	0,000	0,000	0,000	0,006
Jordan	0,000	0,000	0,000	0,042	0,000	0,120	0,000	0,000	0,000	0,000	0,000	0,012
Iran	0,047	0,000	0,000	0,053	0,000	0,300	0,000	0,000	0,000	0,000	0,000	0,029

Table 4.20: Custom Cost of Manufacturers in Two Hubs Included Structure per Item / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Tunus	1,20	0,00	0,00	1,20	1,20	0,00	0,00	1,20	0,00	0,00	1,20	0,00
Tanzania	0,00	0,00	0,00	1,20	0,00	1,20	0,00	0,00	0,00	0,00	0,00	1,20
S. Africa	0,00	1,20	0,00	0,00	0,00	1,20	1,20	0,00	0,00	0,00	0,00	1,20
Jordan	0,00	0,00	0,00	1,20	0,00	1,20	0,00	0,00	0,00	0,00	0,00	1,20
Iran	1,20	0,00	0,00	1,20	0,00	1,20	0,00	0,00	0,00	0,00	0,00	1,20

4.3. Cost Components of the Supply Hubs in Alternate Structure

Similar to manufacturer cost components supply hubs have different cost components. Generally, costs of hubs are generated through the inventory flow between suppliers and supply hubs. These cost components are transportation cost between supplier and hubs, custom related costs, inventory holding cost and ordering cost. Transportation cost data are gathered by addressing to transportation agencies. Please see Table 4.21 for FTL transportation cost, table 4.22 for LTL transportation cost between supply hubs and suppliers for single hub included structures. For two hubs included system FTL costs are updated as illustrated on Table 4.23 and LTL costs are revised as shown in Table 4.24.

Table 4.21: FTL Cost of Hub in One Hub Included Alternate Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	1.190	2.861	2.500	910	100	3.200	1.280	2.500	1.260	1.280	1.008	3.100

Table 4.22: FTL Cost of Hubs in Two Hubs Included Alternate Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	1.190	2.861	2.500	910	100	0	1.280	2.500	1.260	1.280	1.008	0
Dubai	0	0	0	0	0	3.060	0	0	0	0	0	2.465

Table 4.23: LTL Cost of Hub in One Hub Included Alternate Structure/ $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	1.428	3.433	3.000	1.092	120	3.840	1.536	3.000	1.512	1.536	1.210	3.720

Table 4.24: LTL Cost of Hubs in Two Hubs Included Alternate Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	1.428	3.433	3.000	1.092	120	0	1.536	3.000	1.512	1.536	1.210	0
Dubai	0	0	0	0	0	3.672	0	0	0	0	0	2.958

On the other side, other cost variables are exactly the same as manufacturers' cost details on item basis. However these data also altered in order to make them fit into the simulation model. Please see updated hub custom cost per shipment on Table 4.25, hub custom cost per truck on Table 4.26, hub custom cost per unit on Table 4.27 for two supply hubs included alternative. In addition to these cost components, fixed shipment cost details are illustrated with Table 28.

Table 4.25: Custom Cost of Supply Hubs per Shipment for Two Hubs Included Alternate Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,031	0,018	0,003	0,007	0,160	0,000	0,008	0,018	0,010	0,004	0,003	0,000
Dubai	0,000	0,000	0,000	0,000	0,000	0,060	0,000	0,000	0,000	0,000	0,000	0,006

Table 4.26: Custom Cost of Supply Hubs per Truck for Two Hubs Included Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,094	0,053	0,009	0,021	0,481	0,000	0,024	0,055	0,029	0,011	0,010	0,000
Dubai	0,000	0,000	0,000	0,000	0,000	0,180	0,000	0,000	0,000	0,000	0,000	0,019

Table 4.27: Unit Custom Cost of Supply Hubs for Two Supply Hubs Included Structure/ $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	1,2	1,2	1,2	1,2	1,2	0,0	1,2	1,2	1,2	1,2	1,2	0,0
Dubai	0,0	0,0	0,0	0,0	0,0	1,2	0,0	0,0	0,0	0,0	0,0	1,2

Table 4.28: Fixed Shipment Cost of Hubs per Truck for Two Hubs Included Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	200	200	200	200	200	0	200	200	200	200	200	0
Dubai	0	0	0	0	0	200	0	0	0	0	0	200

Similar to these custom related cost details, one hub included structure has the same values. However, these values are updated in order to make them fit into the simulation model as illustrated with Table 29, Table 30, Table 31 and Table 32.

Table 4.29: Custom Cost of Hubs per Shipment for One Hub Included Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,031	0,018	0,003	0,007	0,160	0,060	0,008	0,018	0,010	0,004	0,003	0,006

Table 4.30: Custom Cost of Hubs per Truck for One Hub Included Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,094	0,053	0,009	0,021	0,481	0,180	0,024	0,055	0,029	0,011	0,010	0,019

Table 4.31: Unit Custom Cost of Supply Hubs for One Hub Included Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2

Table 4.32: Fixed Shipment Cost of Supply Hubs per Truck for One Hub Included Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	200	200	200	200	200	200	200	200	200	200	200	200

In terms of ordering cost details please see below Table 4.33 for two hubs included structure and Table 4.34 for one hub included supply chain design.

Table 4.33: Ordering Cost of Supply Hubs per Unit for Two Hubs Included Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,0014	0,0017	0,0014	0,0017	0,0004	0,0000	0,0004	0,0004	0,0036	0,0042	0,0036	0,0000
Dubai	0,0000	0,0000	0,0000	0,0000	0,0000	0,0004	0,0000	0,0000	0,0000	0,0000	0,0000	0,0036

Table 4.34: Ordering Cost of Supply Hubs per Unit for One Hub Included Structure / $

	1	2	3	4	5	6	7	8	9	10	11	12
Turkey	0,0014	0,0017	0,0014	0,0017	0,0004	0,0004	0,0004	0,0004	0,0036	0,0042	0,0036	0,0036

As it can be observed from these cost tables the main difference between one hub included and two hubs included structure is the cost changes in 6th and 12th items. While these items' costs are equal to zero for Turkey hub in two hubs included scenario the situation is vice versa in one hub included structure.

Regarding inventory holding cost of manufacturer and hub in alternate setting, traditional structure's calculation logic is used. For both manufacturer and hub side the average inventory holding cost is \$0,032 as weekly for each unit. In this alternate setting while there is a backorder cost for manufacturer side hubs do not have any back order cost. The reason is that, the entity which has a direct contact with customer is manufacturer itself and for any stock out case manufacturers face with revenue, customer and reputation lost. For this reason, we thought that backorder cost should only be valid for the manufacturer side whereas inventory holding cost incurs for both parties equally. In terms of backorder cost of manufacturer the same calculation logic in traditional setting is followed again. In that calculation backorder cost was \$0,5 per item. The final cost item for alternate structure is annual renting and operating cost of hubs. We ask industry advisors about what may be a cost of a warehouse that will be able to handle mentioned inventory amount in our model. As a result of these industry advices, we have calculated a fixed annual renting and operating cost for both Turkey and Dubai Hubs as 1 million USD dollars. Thus, in one hub and two hubs included scenarios these costs are included and added to the total system cost.

4.4. Main Settings and Cost Formulations in Simulation Model for Alternate Supply Chain Design

Modeling concept of alternate supply chain designs where hubs are located between the flows of manufacturers and suppliers is quite similar to traditional structure's setting. Similar to traditional structure's simulation model, alternate structure's model starts with demand entity creations blocks which are again totally six blocks each represents a single manufacturer. These blocks are creating demand of manufacturer for each item of manufacturer with an exponential distribution with a mean 7 days as same as traditional structure. After these creations, entities are entered into the assign block where their item and plant numbers are assigned. Please see Table 4.35 for revised assign variables used in simulation model. After a decision box they are again entered in another assign blocks and each item as an attribute has been attributed with a normally distributed demand and a specific standard deviation ratio. In this point each attribute has a unique item, plant and demand information.

Thereafter different than the traditional structure unique entities follow to another assign block where items are attributed to a specific supply hub. In this sections if the supply chain structure is based on single hub then all items are attributed to that single assign. Otherwise, in two hubs included structures items are assigned according to desired match of items and hubs. For example, in two hubs included structure item 6 and item 12 are assigned to hub number 2 which is Dubai hub. In other scenario since there is a single hub that is Turkey, all items are assigned to Turkey hub. After this assignment, entities follow the same order as in traditional model where all entities follow a decision box about whether on hand plant inventory is satisfying the demand or not. If the demand is satisfied the entities are updating both physical inventory and inventory position and reach the decision module where the decision of creating a purchase order is necessary or not is taken. In other case, if the demand is not fully satisfied, existing inventory satisfies some proportion of demand and again update the inventories by equating physical inventory to zero. After this point, entities again reach to ordering decision box. Before coming to this ordering decision module another vital point is the calculation of fill rate i.e. the proportion of demand that is satisfied from existing physical inventory which is again the same structure in traditional model. Equation 3.3 for total demand calculation, equation 3.4 for satisfied demand calculations and equation 3.5 for fill rate calculation details which had been already illustrated in traditional model setting section are also valid for this setting. In order to calculate this fill rate total demand and total satisfied demand variables for each plant and item is kept as a two dimension variable. All variables used in alternate supply chain structures of the company are illustrated in Table 4.36.

Table 4.35: Definition and Calculation Details of Attributes in Alternate Supply Chain Model

Attributes	Defition of Attributes	Calculation Details
Demand	Unique demand values which are assigned to single item, plant	Company weekly demand data is used with normal distribution and spesific standart deviation rate such as (%10, %30 and %60)
Hubnumtruckload	Remainder of hubtruckload value that is subtracted form integer hubtruckload value	hubtruckload - AINT(hubtruckload)
Huborderqty	Purchase order quantities of hubs that will be released to related supplier	Hub big S(hubassign,item) - Inventory position of hub(hubassign,item)
Hubtruckload	Number of trucks that is required to transport materials from suppliers to supply hubs	huborderqty / trucksize(item)
Numtruckload	Remainder of truckload value that is subtracted form integer truckload value	Truckload - AINT(truckload)
Orderqty	Purchase order quantities of plants that will be released to related supply hub	Big S - inventory position(plant,item)
Truckload	Number of trucks that is required to transport materials from supply hubs to plants	Orderqty / Trucksize(item)

Table 4.36: Parameters Used in Simulation Model for Alternate Supply Chain Structure of the Company

Variables	Defition of Variables
Back order cost (plant,item)	Unit cost of unsatisfied plant demand
Big S (plant,item)	Order up to level of plant for each item
Custom cost (plant,item)	Total custom cost which includes summation of custom cost per shipment, custom cost per truck, unit custom cost and fixed shipment cost
Custom cost per shipment(plant,item)	Custom cost that is paid by manufacturer for each single shipment
Custom cost per truck(plant,item)	Custom cost that is paid by manufacturer for each truck
Demand satisfied (plant,item)	Total demand of plant that is satisfied from physical inventory (met demand of plant)
Fill rate (plant item)	Rate of satisfying the manufacturer demand by using physical ineventory with an equation of demand satisfied(plant,item) divided by total demand (plant,item)
FTL cost (plant,item)	Full truck load (FTL) cost of manufacturer for each item which is supplied by a single supplier
FT transport cost (plant,item)	Total FT costs that incurs for each plant
Hub big s(hubassign,item)	Order up to level of hub for each item
Hub custom cost(hubassign,item)	Total custom cost of hub which includes summation of custom cost per shipment, custom cost per truck, unit custom cost and fixed shipment cost of hubs
Hub custom cost per shipment(hubassign,item	Custom cost that is paid by hub to supplier for each single shipment
Hub cutom cost per truck(hubassign,item)	Custom cost that is paid by hub to supplier for each truck
Hub FTL cost(hubassign,item)	Full truck load (FTL) cost of hub for each item which is supplied by a single supplier
Hub item(hubassign,item)	Item-hub assignment
Hub lead time (item)	Lead time of hub for each item from a unique supplier
Hub little s(hubassign,item)	Safety stock level of hubs for each item
Hub LTL cost(hubassign,item)	Less than truck load (LTL) cost of hubs for each item which is supplied by a single supplier
Hub shipment cost	Fixed cost of making a shipment from supplier for hub
Hub transpot cost ft(hubassign,item)	Total FTL costs that incurs for each hub
Hub transpot cost ltl(hubassign,item)	Less than truck load (LTL) cost of hub for each item which is supplied by a single supplier
Hub unit custom cost(hubassign,item)	Unit custom cost of hub for each item
In transit inventory (plant,item)	Inventory that is ordered by plant from hub and on in transit
In transit inventory of hub(hubassign,item)	Inventory that is ordered by hub from supplier and on in transit
Inventory (plant,item)	Physical plant inventory
Inventory of hub(hubassign,item)	Physical hub inventory
Inventory position (plant,item)	Summation of inventory (plant,item) and intransit inventory (plant,item)
Inventory position of hub(hubassign,item)	Summation of inventory of hub (plant,item) and intransit inventory of hub (plant,item)
Lead time (plant,item)	Lead tim of each item for manufacturers
Little s (plant,item)	Safety stock level of manufacturers for each item
LTL cost (plant,item)	Less than truck load (LTL) cost of manufacturers for each item which is supplied by a single supply hub
LTL transport cost (plant,item)	Summation of total LTL costs that incurs for each plant
Material cost (item)	Purchasing cost of each item
Ordering cost (plant,item)	Cost of ordering a single unit from hub for plant
Ordering cost of hub(hubassign,item)	Cost of ordering a single unit from supplier for hub
Shipment cost	Fixed cost of making a shipment from hub for plant
Total demand (plant,item)	Total demand that is entered into the system for each item and manufacturer
Total ordering cost (plant,item)	Total ordering cost of manufacturer for each item which is calculated as a summation of FTL, LTL transportation costs, ordering setup cost and material cost
Total ordering cost of hub(hubassign,item)	Total ordering cost of hub for each item which is calculated as a summation of FTL, LTL transportation costs of hub and ordering setup costs of hub
Truck size (item)	Capacity of a truck for a single item for all entities
Unit custom cost (plant,item)	Unit custom cost of plant for each item
Unit holding cost (plant,item)	Unit holding cost of manufacturer for each item

As in the traditional setting, after these inventory updates and fill rate calculations, inventory controlling module takes place. This decision box checks whether below equation 4.4 is valid or not. If this equation is valid, there is no need for a purchase order so the entity leaves the system with a dispose block otherwise the entity goes to an assign block to calculate order amount. It is important that this inventory check is fulfilled with not only checking physical inventory level but also in transit inventory level. It might be useful to mention once again that inventory position is the summation of physical inventory and in transit inventory.

Equation 4.4

Inventory position (plant,item) > ***little_s (plant,item)***

In terms of plant purchase order quantity calculation, below simple equation 4.5 is being used. It is important to remind that as illustrated on Table 4.35 order quantity is an attribute that have information of demand value for a plant and a single item whereas *S* and inventory position are two dimension variables as illustrated on Table 4.36.

Equation 4.5

Orderqty = big_s(plant,item) – inventory position(plant,item)

After order calculation block order processing process starts as illustrated with other operations used in simulation model with Table 4.37. This operation is exactly the same as in real life in terms of order quantity calculation by planning department and then order release by purchasing department.

Table 4.37: Main Operations Used in Simulation Model for Alternate Supply Chain Structure of the Company

Operation Name	Definition of Operation	Operation Lenght
Order preparation and consolidation of hub	Order preparation process of hub that is start with an order receipt from manufacturer and ends with making related materials ready for shipment. Within this period plant orders are also consolidated if possible.	NORM(6, 1) days
Order Processing of plant	Order creation and releasing process of manufacturers for a single purchase order	NORM (3,1) hours
Order Processing of hub	Order creation and releasing process of hub for a single purchase order	NORM (3,1) hours
Transportation of plant	Transportation of materials from hubs to plants	NORM(Lead time(plant,item),0,1*/Lead time(plant,item)) days
Transportation of hub	Transportation of materials from suppliers to hubs.	NORM(Hub lead time(plan,item),0,1*/Hub lead time(plant,item)) days

Up to this point, except from item supply hub assignment the flow of simulation model is exactly the same as the setting of traditional simulation model. In former traditional setting, after this point order is passed to supplier. However in this alternate structure purchasing order is sent to supply hubs where orders are consolidated on manufacturer base. After orders are received by supply hubs there is another physical inventory check whether a supply hub can satisfy the demand of manufacturer or not. If the demand is fully satisfied in this point orders are directly enter in order preparation part where orders are waits about 6 days which is quite higher than the traditional setting. This order preparation and consolidation operation that is illustrated in Table 4.37 takes 6 days on average with a standard deviation of 1 day in normal distribution. Within this order preparation time the orders are waited and if another order received from the same manufacturer for the same hub, they are consolidated and shipped together to the receiving part i.e. manufacturer. The reason of establishing such an order consolidation setting in alternate structure is that hubs do not have a single unique material as in the case of traditional setting such as suppliers. Since they have multiple items in their inventory we think that order consolidation is a necessary setting in this alternate structure. In the meantime, we want to measure the opportunity of using such a consolidation structure and find out that without having order consolidations setting the transportation costs are 6% higher than the order consolidation included simulation model. If plant order quantity cannot be satisfied by the supply hub then order quantity is revised as supply hubs' physical inventory. After this order quantity update orders again enters in order preparation and consolidation processes.

In contrary to traditional setting, we do not assume that supply hubs have always infinite capacity to satisfy manufacturer's demand. In this alternate setting, supply hubs are also work with a *s,S* inventory management policy as the manufacturer sides. With this policy, hubs are keeping stock according to ROP with *hub little_s* variables which are calculated based on the 98% service level calculation by using the lead time demand between supply hubs and suppliers. Thus, there is a probability of being stock out on the supply hub side. On contrary to manufacturer side there is no fill rate calculation for hubs since the main focus on this study is measuring the costs and customer service levels of manufacturers.

In this alternate setting, manufacturers' inventory management policy is the same as in tradition setting. When an order is received by hub and confirmed the plant order quantity, necessary inventory updated are made with equations 3.8, and 3.9 that are illustrated in previous traditional structure's simulation setting section. Equation 3.8 updates in transit inventory of plant and then with equation 3.9 inventory position of plant is updated. Hub side inventory management has the same logic with the manufacturer side. Please see equation 4.6 and 4.7 where hubs' physical inventory and inventory position calculations take place respectively. Similar to traditional setting when an order from manufacturer received by a hub, after physical inventory check, if inventory satisfy plant's order quantity hub's physical inventory is updated as illustrated with equation 4.6. Similar to traditional setting logic, when physical inventory and in transit inventories of hubs are updated inventory position of hub's should be also calculated since hubs' order quantities are calculated by using hubs' inventory position level as it is same in manufacturer side. Thus, after physical inventory update of hub, inventory position is updated accordingly as shown in equation 4.7.

Equation 4.6

Inventory of hub(hubassign,item) = Inventory of hub(hubassign,item) - orderqty

Equation 4.7

Inventory position of hub(hubassign,item) = inventory of hub(hubassign,item) + intransit inventory of hub(hubassign,item)

After manufacturer and hub sides' inventory updates, a few calculations follow the system such as truckload value and remainder of truckload calculations as they are the same as in traditional structure's simulation setting. Please see truckload and remainder of truck load calculation equations respectively with equations 3.10 and 3.11 that are indicated in previous model setting. Please note that *truckload* and *numtruckload* values are attributes as they are shown in updated attributes Table 4.35. The reason of calculation *numtruckload* value is to calculate LTL cost in hub included structure easily. Furthermore, since our LTL costs are full truck load cost it is convenient to use remainder of truckload which is *numtruckload* attribute in our simulation model.

After these unique values are calculated transportation costs of manufacturers are calculated with the same logic in traditional setting. Similar to previous traditional structure 72% percent logic is used in this structure. This transportation cost calculation setting enable to replicate the real life case. In real life using a LTL or FTL is decided by the purchasing department by considering volume and weight ratio. This case is simulated with this clever setting as same as in real life. We believe that this setting is one of the advantages in this model which enable to replicate a detailed but important operation insight in real life and save in transportation cost. Related calculation details were already discussed in previous traditional structure with equation 3.12, equation 3.13 and 3.14. If equation 3.12 is valid than the entity follows equation 3.13 and calculate LTL transportation cost calculation, otherwise equation 3.14 is used to for FTL transportation cost calculation. In the meanwhile, while computing these costs updated FTL and LTL cost variables that are illustrated on Table 4.11 and Table 4.12 for one hub included system and Table 4.16 and Table 4.17 that are illustrated in previous cost component section for two hubs included structure are used. Since lead time between hubs and manufacturers is completely different than the traditional setting i.e. the lead time between supplier and manufacturers, transportation costs are updated with these tables accordingly.

After calculation of transportation costs the model is followed by the calculation of plant’s total custom cost as it is also in the case in traditional setting. Total custom cost is composed of the same various costs as they are illustrated with equation 3.15 in previous tradition model’s setting section. However, as it is in the case of transportation cost case; these custom related cost variables are updated with the introduction of hubs in this alternate structure. These costs are re-calculated twice since there are two different scenarios in hub included structure. Please see Table 4.13, Table 4.14, and Table 15 that are illustrated in previous section for the components of total custom cost in one hub included structure. For two hubs included structure these manufacturer costs are updated accordingly as shown in Table 4.18, Table 4.19 and Table 4.20

Thereafter these manufacturers’ cost calculations, entities separated into two by using separation module’s duplicate original type with 100% duplications entities follow two different sections. One of the sides of these sections, manufacturer related inventory updates and calculations are fulfilled whereas in other side hub related inventory updates and calculations are made.

In terms of manufacturer updates, entities follow transportation process where specific lead times between hub and manufacturers takes place with a 10% standard deviation which is also so similar to real life case and written in transportation process module as a value of *NORM (leadtime(plant,item), 0.1*leadtime(plant,item)).* In the meantime, all processes used in this alternate structure is demonstrated in Table 4.37 whereas updated lead times between manufacturers and hubs are illustrated in Table 4.5 as an example of one hub included structure. Lead times differ from each other for each alternate scenario since they are supplied by various supply hubs in these two alternate structures. After this transportation lead time, inventory update of manufacturer is made with the same equation 3.16 that is illustrated in section 3. With this update as it is usual in transit inventory and inventory position of plant are also revised as equation 3.17 and 3.18 in section 3. After these inventory updates, as a last step of manufacturer side total ordering cost is calculated with the same way in traditional structure as illustrated with equation 3.16 in section 3.

Simulation model continues with the hubs' inventory updates and cost calculations. After calculation of manufacturers' costs and inventory updates of manufacturers and hubs as a second step, inventory position of hub is checked and if inventory position of hub is less than hub ROP level for a specific item as shown with equation 4.8 then order quantity of supply hub is calculated. In meantime, equation 4.9 illustrates the calculation logic of hubs' ROP (*hub little_s*) values. Moreover, equation 4.10 indicates the calculation of hub order quantities in simulation model.

Equation 4.8

Inventory position of hub (hubassign,item) ≤ hub little_s(hubassign,item)

Equation 4.9

Hub little_s(hubassign,item) = Sum (Lead time demand (plant,item) + (standard deviation*weekly demand*(√(lead time))*2,06))

In equation 4.9, as a lead time, the lead time between hub and supplier is used with weekly basis. Moreover, the fixed value i.e. 2,06 comes from the normal distribution table where 98% service level is achieved. In addition, there are three different standard deviation ratios which are 10%, 30% and 60%. These alternatives are used for alternate scenarios with the same logic in traditional structure.

Equation 4.10

Huborderqty = Hub big_S(hubassign,item) - Inventory position of hub(hubassign,item)

Hub order up to levels (S values) are calculated by summing ROP (s) values and $Q*$ (optimum order quantity) values of hub. Please see equation 4.11 for the calculation of hub $Q*$ values. In short, hub $Q*$ values are calculated with a summation of plants' optimum order quantities. Moreover, equation 4.12 illustrates how hub order up to levels (S values) is calculated.

Equation 4.11

$$\boldsymbol{hub\ Q*(hubassign, item)} = [\sum_{\boldsymbol{hubassign}=1}^{\boldsymbol{2}} \sum_{\boldsymbol{item}=1}^{\boldsymbol{12}} \boldsymbol{Q}*]$$

Equation 4.12

Hub big_S(hubassign,item) = hub little_s(hubassign,item) – hub Q*(hubassign,item)

After order quantities of hubs are calculated hubs' order processing which is similar to plants' duration of this order processing has a value of 3 hour as a mean and a standard deviation of 1 hour. Please see table 4.37 for the processes used in this model. After an entity pass through this module in simulation it comes to two different assign blocks where hub truck load amount and the remaining of the integer part of hub truck load (*hubnumtruckload*) is calculated. Please see equation 4.13 for hub truck load calculation and equation 4.14 for the calculation of the remaining part of the integer value of hub truck load.

Equation 4.13

Hubtruckload = huborderqty / trucksize(item)

Equation 4.14

Hubnumtruckload = hubtruckload - AINT(hubtruckload)

Please note that *hubtruckload* and *hubnumtruckload* values are attributes as they are shown in Table 4.37. The reason of calculation *hubnumtruckload* value is to calculate hub LTL costs easily. Since our hub LTL costs are full truck load cost it is convenient to use remainder of truckload which is *hubnumtruckload* attribute in our simulation model.

In terms of the calculation of hubs' transportation costs the same logic that is used in traditional setting which is 72% is also used in this model. Since it is more advantageous to use FTL instead of LTL when truck load is more than 72% percent, the model automatically calculate FTL cost if *hubnumtruckload* is more than 72% of the truckload. For this reason we have replicate this situation also in our alternate model as it is by using a decision box that include equation 4.12 and by using different calculation types as illustrated in equation 4.13 and 4.14. If equation 4.15 is valid than the entity follow equation 4.16 and calculate LTL transportation cost calculation otherwise equation 4.17 is used to for FTL transportation cost calculation. By the way while computing these cost FTL and LTL cost variables that are illustrated on Table 4.21, Table 4.22 Table 4.23 and Table 4.24 are used.

Equation 4.15

Hubnumtruckload < 0.72

Equation 4.16

Hubtransportcostltl(hubassign,item) = (hubtransportcostltl(hubassign,item) + (AINT(hubtruckload) * hubftcost(hubassign,item)) + (hubnumtruckload * hubltlcost(hubassign,item))

Equation 4.17

Hubtransportcostft(hubassign,item) = (Hubtransportcostft(hubassign,item) + (AINT(hubtruckload) + 1)* hubftcost(hubassign,item)

Different than the tradition structure's simulation model this alternate structure's model is also dealing with another important operation which is increasing the order quantity of hubs (*huborderqty* values) in the case of *hubnumtruckload* attribute is more than 72%. If equation 4.15 is valid, order quantity of hub (*huborderqty* value) is increased to full truck size. The logic of including such as logic in this model is that we thought that since hubs are working as a consolidation point and shipping big quantities of plants' orders, increasing *hubnumtruckload* to an integer i.e. a full truck load will prevent carrying empty trucks from suppliers. In short, by adding such a system in this model we achieved that all trucks loaded on supplier sides will be fully loaded if *hubnumtruckload* value is larger than 72%. The equation that is written in our simulation model is shown with equation 4.18. In the meantime, *trucksize* used in this alternate model for the hub side is exactly the same as in traditional setting. The reason of this is that the truck sizes are always the same.

Equation 4.18

Huborderqty = (1 + AINT(hubtruckload)) * trucksize(item)

After calculation of transportation costs the model is followed by the calculation of hubs' total custom cost. Total custom cost of hub is composed of various costs as it is illustrated with below equation 4.19. Please see Table 4.25, Table 4.26, Table 4.27, Table 4.28, Table 4.29, Table 4.30, Table 4.31 and Table 4,32 for the components of hubs' total custom cost.

Equation 4.19

Hubcustomcost(hubassign,item) = hubcustomcost(hubassign,item) + hubshipmentcost + hubcustomcostpershipment(hubassign,item) + hubcustomcostpertruck(hubassign,item) + (huborderqty*hubunitcustomcost)

After calculation of these costs in transit inventory and inventory position of hubs are updated. Please see equation 4.20 for the calculation of hub in transit inventory and equation 4.21 for the calculation of inventory position of hub. In all simulation models we built the sequence of inventory position, in transit inventory and inventory update modules are the same sequence where in all cases inventory and in transit inventory update take place first and then inventory positions are updated since in inventory position is a variable that include both the variables of physical and in transit inventory.

Equation 4.20

Intransitinventoryofhub(hubassign,item) = intransitinventoryofhub(hubassign,item) + huborderqty

Equation 4.21

Inventoryofhub(hubassign,item) = inventoryofhub(hubassign,item) + intransitinventoryofhub(hubassign,item)

After these inventory updates transportation lead time takes place. As an example of transportation lead time of hubs Table 4.5 shows single hub included structures lead times of Turkey hub. After a specific lead time hubs are receiving the materials physically and in this point physical inventory, in transit inventory and inventory position of hubs are updated. Physical inventory update is shown with below equation of 4.22, in transit inventory update is illustrated with equation 4.20 and finally inventory position is updated with an equation 4.21.

Equation 4.22

inventoryofhub(hubassign,item) = inventoryofhub(hubassign,item) + huborderqty

Before running the simulation model initial inventory levels of manufacturers are defines as up to inventory levels of which means beginning inventory levels of manufacturers are equal to *S* values as illustrated with equation 4.23 below.

Equation 4.23

inventory(plant,item) = big_S(plant,item) = inventory position(plant,item)

The same logic for beginning inventory level is also followed on the hub side. Before running the model initial inventory position and physical inventory levels are defined as the order up to point level of hubs as illustrated with below equation 4.24. The logic of these two equations is that we assume that both manufacturers and hubs have enough inventory for each item at the beginning of the model run.

Equation 4.24

Inventory of hub(hubassign,item) = hub big_S(hubassign,item) = inventory position of hub(hubassign,item)

In order clarify the alternate business model Figure 4.2 illustrate the main setting in alternate procurement model.

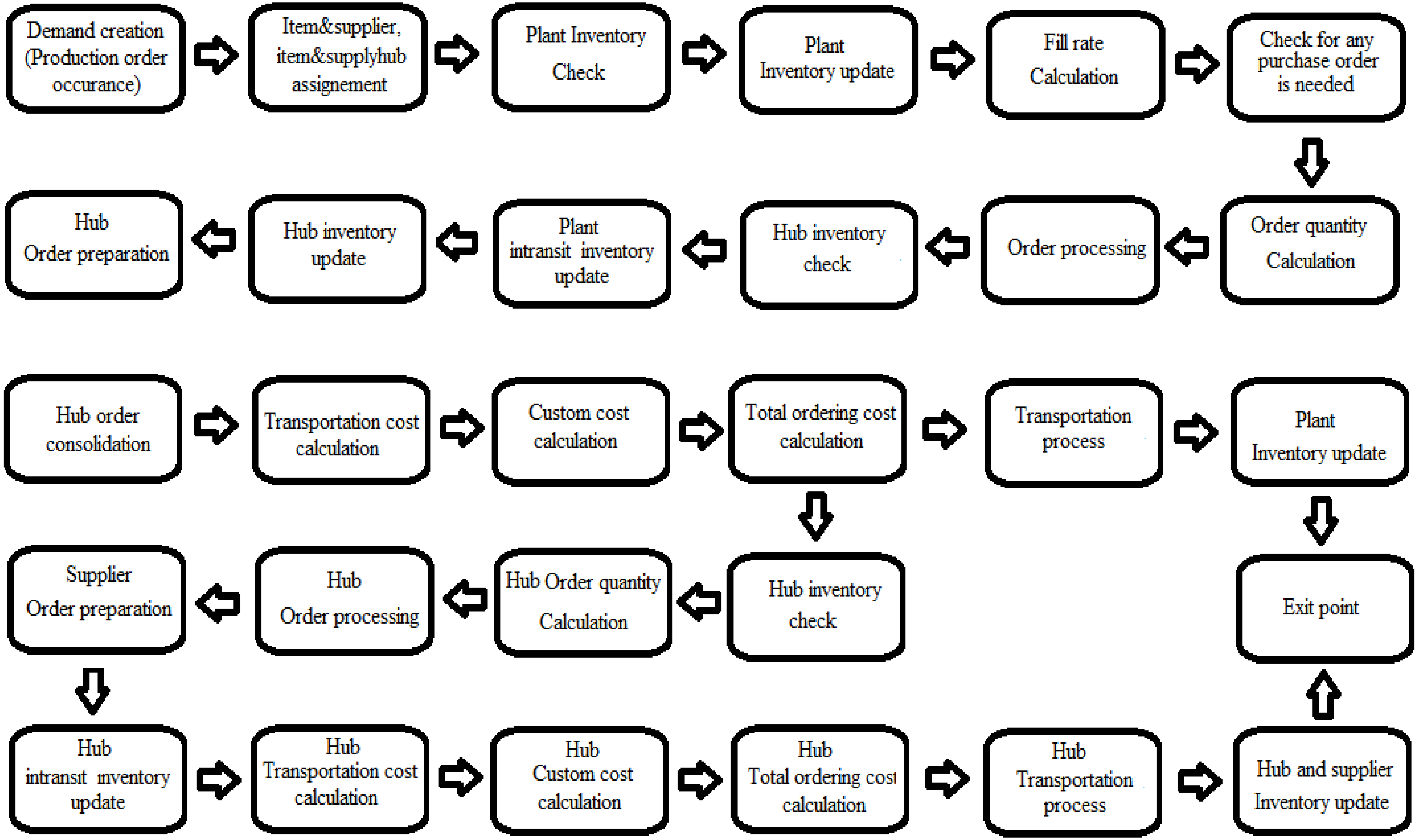


Figure 4.2: Main setting of simulation model for alternate procurement structure

CHAPTER V

APPLICATION RESULTS

In this output section both the result of simulation model of current supply chain structure and alternate supply chain design (one hub and two hubs included structures) are analyzed with various tables and figures. The section is divided into two main parts which firstly introduce the outputs of the current supply chain design and then the result of alternated supply chain designs.

5.1. Outputs of the Simulation Models

Before running each model, model inputs are prepared for each scenario. These inputs are illustrated in Table 4.36. After the setup of the simulation models for each alternative i.e. no hub included, one hub included and two hubs included structures each model is run with various alternative scenarios for the current business procurement system for 365 days as a run time with a warm up period of 365 days. In terms of number of replication the model runs 10 times in order to provide a report. After running with warm up period for each replication Arena creates a report in terms of the statistics we have required and written down such as total custom cost, total ordering cost, average inventory level, fill rate and so on. All statistics used in 81 different models are illustrated on Table 5.1 below.

Table 5.1: Statistics Kept in Simulation Model

Custom cost (plant,item)
Demand satisfied (plant,item)
FT transport cost (plant,item)
Hub custom cost(hubassign,item)
Hub transpot cost ft(hubassign,item)
Hub transpot cost ltl(hubassign,item)
In transit inventory (plant,item)
In transit inventory of hub(hubassign,item)
Inventory (plant,item)
Inventory of hub(hubassign,item)
LTL cost (plant,item)
LTL transport cost (plant,item)
Supinventory (supplierassign,item)
Total demand (plant,item)
Total ordering cost (plant,item)
Total ordering cost of hub(hubassign,item)

As a result, model provides values of these statistics as an average of 10 replications. Physical and in transit inventories of manufacturers and hubs are kept as a statistics in order to illustrate average inventory level of each model and compare them in terms of inventory holding costs. Moreover, supplier inventory statistics kept in order to demonstrate the whole supply chain's total inventory. Total demand and demand satisfied statistics are used to calculate manufacturers' fill rate ratio. With this logic, fill rate represent the ratio of demand that is satisfied by the physical inventory. Total ordering cost which includes material, ordering, transportation costs and custom cost which includes total custom cost are used to calculate total entity cost. In addition to these costs, total entity cost has two cost components which are inventory holding and backorder cost. However, while calculating hubs' entity cost back order cost is not considered since backorder is only take place in manufacturer side. However, inventory holding cost is calculated for both parties in hub included scenarios. While calculating entity cost of hub side another cost component which is annual renting and operating cost of hub is added to the hub entity cost. Finally, total cost as a system wide in hub included structure is calculated by summing total entity costs of plant and hub side.

For the current business structure the model is run 27 times with different values for different scenarios. In terms of these scenarios we have determined three different scenario sets which are demand ratio as medium, low and high; standard deviation ratio as 10%, 30% and 60%; and finally service type as company policy, 90% and 98% service levels. In terms of one hub and two hubs included scenarios the same scenario sets are used and 27 scenarios for each supply chain structure are prepared and totally 81 different scenario results are obtained.

In terms of demand rate scenario we have taken medium demand as company's current situation in terms of weekly demand whereas low demand is taken as the half of the medium demand and high demand represent 1,5 times of the current demand data. We have determined these demand levels as moderate, bad and good sales scenarios in the market. We thought that it will be good for the company to review different sales scenarios which can be changed easily by the changing attitudes of consumers in today's global conditions.

With respect to standard deviation of demand we define again three different scenarios such as low fluctuated demand with a 10% standard deviation, moderately fluctuated demand with a 30% standard deviation and finally highly fluctuated demand with a 60% standard deviation.

Finally, regarding the last scenario component i.e. service level we use company policy as a base scenario which says hold ROP level as lead time demand plus 1 moth demand. As an alternative of this company policy, we use 90% and 98% type 2 service levels which illustrate the satisfaction of demand form the on hand inventory. If company choses 90% service level, it will be able to cover 90% of the total demand from its stock in the first alternative scenario. Similarly, when 98% service level is used 98% of the total demand will be satisfied from the on hand inventory. While calculating these values normal distribution table is used.

For all of these different scenarios all data as model inputs are updated accordingly. For example, for demand rate scenarios demands, ROP and order up to levels are updated as moderate, low and high and put in the model. Similarly, in terms of standard deviations the same variables and model updated with new values. In terms of service level scenarios ROP (*s*) levels are updated accordingly. Please see Table 3.6 for the ROP that are calculated according to company, Table 3.8 ROP stock levels with 98% service level and Table 3.7 for ROP values for 90% service level. As it can be observed from the values, company policy requires considerably high level of ROP compared to 90% and 98% service levels where there is a small difference between 90% and 98% ROP levels. Similar to ROP levels in all alternatives the same logic is followed for order up to levels (*S*) and all data in simulation model is updated with new values as well.

5.2. Outputs of the Current Supply Chain Structure (No Hub Included)

After running 27 different models with updated variable and model settings Arena simulation models' reports are exported to excel files. Thereafter inventory holding cost and backorder cost calculations are completed by using average inventory levels of each model and then all data are gathered in a report of excel file that illustrate the whole total cost details and fill rates for each alternatives. The summary of this report as an output of these 27 different scenarios is illustrated with Table 3.23. This table represent whole cost details for each alternative with average inventory levels, fill rates and custom, ordering, inventory holding, back order and total plant cost details.

Table 5.2: Model Outputs of No Hub Scenario / Million / $

Alternative system	Number of hubs	Demand ratio	Standard deviation	Service type	Entity	Custom cost	Total ordering cost	Average inventory level	Average intransit level	Average supplier inventory	Average entity inventory	Inventory holding cost	Back order cost	Renting and operating cost of hub	Entity cost	Total cost	Fill rate
1	No hub	Medium	0,1	0,9	Plant	8,6	57,3	0,42	0,44	0,64	0,85	1,6	17,1	-	84,5	84,5	92,0%
2	No hub	Medium	0,3	0,9	Plant	8,8	58,8	0,46	0,45	0,66	0,91	1,7	11,7	-	80,9	80,9	94,5%
3	No hub	Medium	0,6	0,9	Plant	8,9	59,6	0,55	0,46	0,69	1,00	1,8	9,6	-	79,9	79,9	95,5%
4	No hub	Medium	0,1	0,98	Plant	8,8	58,8	0,43	0,44	0,64	0,87	1,6	17,0	-	86,2	86,2	92,3%
5	No hub	Medium	0,3	0,98	Plant	8,8	59,1	0,51	0,46	0,68	0,97	1,8	7,7	-	77,4	77,4	96,3%
6	No hub	Medium	0,6	0,98	Plant	9,3	62,6	0,64	0,47	0,70	1,11	2,0	5,7	-	79,6	79,6	97,4%
7	No hub	Medium	0,1	company policy	Plant	9,6	64,9	0,80	0,50	0,73	1,30	2,3	1,2	-	78,1	78,1	99,4%
8	No hub	Medium	0,3	company policy	Plant	9,5	63,6	0,84	0,49	0,74	1,33	2,4	1,0	-	76,5	76,5	99,5%
9	No hub	Medium	0,6	company policy	Plant	9,5	63,8	0,93	0,50	0,73	1,42	2,5	1,1	-	77,0	77,0	99,5%
10	No hub	Low	0,1	0,9	Plant	4,5	27,1	0,24	0,23	0,34	0,48	0,9	7,1	-	39,5	39,5	93,7%
11	No hub	Low	0,3	0,9	Plant	4,4	26,4	0,27	0,23	0,34	0,50	0,9	4,7	-	36,3	36,3	95,7%
12	No hub	Low	0,6	0,9	Plant	4,4	26,8	0,31	0,23	0,35	0,55	1,0	4,0	-	36,2	36,2	96,3%
13	No hub	Low	0,1	0,98	Plant	4,4	26,2	0,26	0,23	0,34	0,48	0,9	5,4	-	36,8	36,8	95,0%
14	No hub	Low	0,3	0,98	Plant	4,6	27,4	0,29	0,24	0,35	0,53	1,0	3,6	-	36,5	36,5	96,7%
15	No hub	Low	0,6	0,98	Plant	4,7	28,4	0,36	0,24	0,36	0,61	1,1	2,4	-	36,7	36,7	97,8%
16	No hub	Low	0,1	company policy	Plant	4,9	29,3	0,45	0,25	0,37	0,70	1,2	0,7	-	36,1	36,1	99,4%
17	No hub	Low	0,3	company policy	Plant	4,8	29,0	0,47	0,25	0,37	0,72	1,3	0,5	-	35,6	35,6	99,5%
18	No hub	Low	0,6	company policy	Plant	4,9	29,5	0,51	0,25	0,36	0,76	1,4	0,6	-	36,4	36,4	99,4%
19	No hub	High	0,1	0,9	Plant	12,7	81,4	0,54	0,66	0,94	1,20	2,2	24,7	-	121,1	121,1	92,2%
20	No hub	High	0,3	0,9	Plant	13,4	85,3	0,61	0,68	1,00	1,29	2,4	21,6	-	122,7	122,7	93,3%
21	No hub	High	0,6	0,9	Plant	13,8	87,9	0,72	0,72	1,07	1,43	2,6	19,9	-	124,2	124,2	94,0%
22	No hub	High	0,1	0,98	Plant	13,1	84,4	0,56	0,67	0,98	1,23	2,3	26,4	-	126,2	126,2	92,0%
23	No hub	High	0,3	0,98	Plant	13,9	89,3	0,69	0,69	1,03	1,39	2,6	17,1	-	122,8	122,8	94,9%
24	No hub	High	0,6	0,98	Plant	13,9	90,2	0,88	0,71	1,03	1,59	2,9	9,8	-	116,8	116,8	97,0%
25	No hub	High	0,1	company policy	Plant	15,0	97,5	1,11	0,76	1,13	1,87	3,4	2,4	-	118,3	118,3	99,3%
26	No hub	High	0,3	company policy	Plant	14,7	95,0	1,22	0,72	1,04	1,94	3,5	3,0	-	116,1	116,1	99,1%
27	No hub	High	0,6	company policy	Plant	14,8	96,0	1,32	0,73	1,07	2,05	3,7	2,2	-	116,7	116,7	99,3%

When the outputs of current supply chain design for different scenarios are analyzed, it can be observed that there is a direct proportion between amount of ROP and demand fill rate. As it can be observed from Table 5.2, when service type is 90% fill rates are their lowest percentage in all scenarios compared to 98% and company policy service level type. Similarly for all scenarios, 98% service levels have less percentage in terms of fill rates when it is compared with company policy. As it can be observed from Figure 5.1 total cost is lowest in company policy service level case with 78 million USD dollars while demand fill rate is at the highest level with 99 percent. Of course this result is not surprising in terms of fill rate because it validates a motto that the higher inventory level a company has, the higher customer service level it will have. However, total cost values in the same figure may a little be surprising. Because, one may think that if a company has less inventory in its facility it should have less total cost. This logic is valid in terms of total ordering and inventory holding cost as they are illustrated in Figure 5.2 and Figure 5.3. However, while calculating total plant cost there is another cost component which is backorder cost. Since unit backorder is quite higher than the inventory holding cost, total cost graph has showed the lowest value in the company policy case where inventory level is the highest ratio. Please see Figure 5.3 and for the effect of back order cost on total cost compared to inventory holding cost.

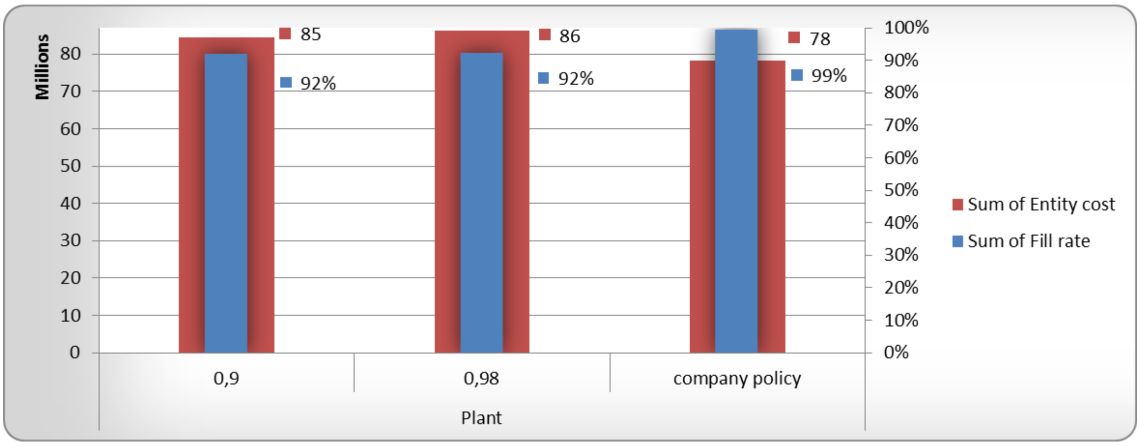
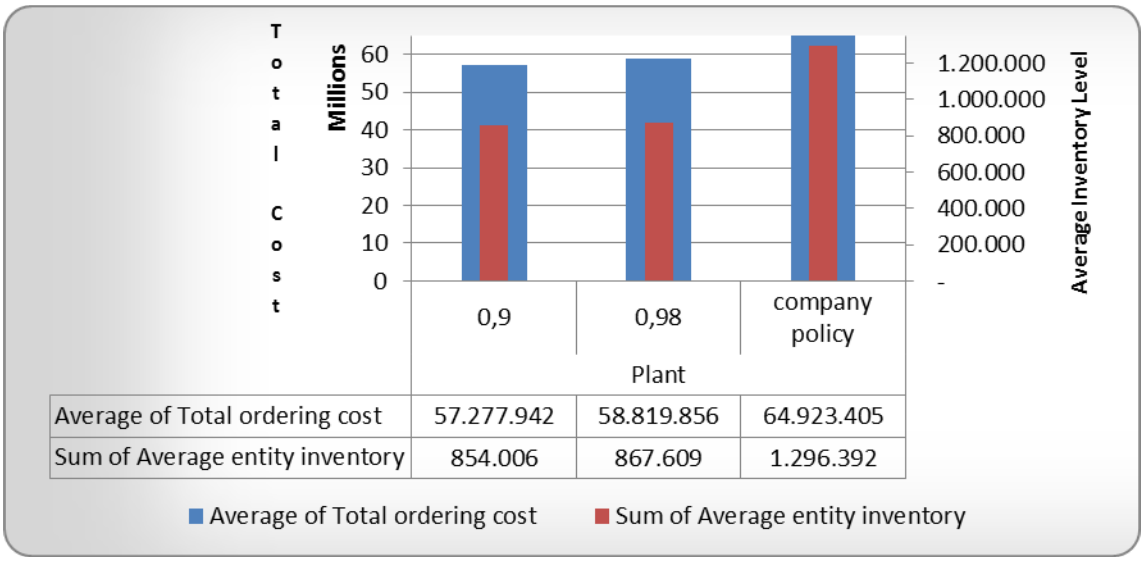
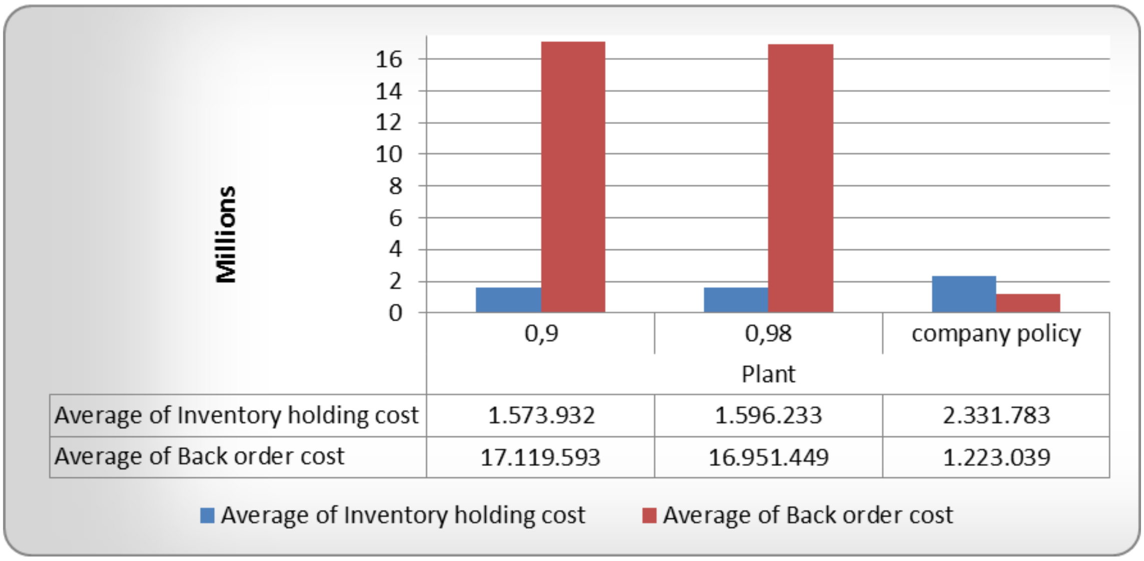


Figure 5.1: Total Cost and Fill Rate Comparison under Different Service Levels for No Hub, Medium Demand and 10% Standard Deviation Scenario / Million / $



Plant	0,9	0,98	company policy
Average of Total ordering cost	57.277.942	58.819.856	64.923.405
Sum of Average entity inventory	854.006	867.609	1.296.392

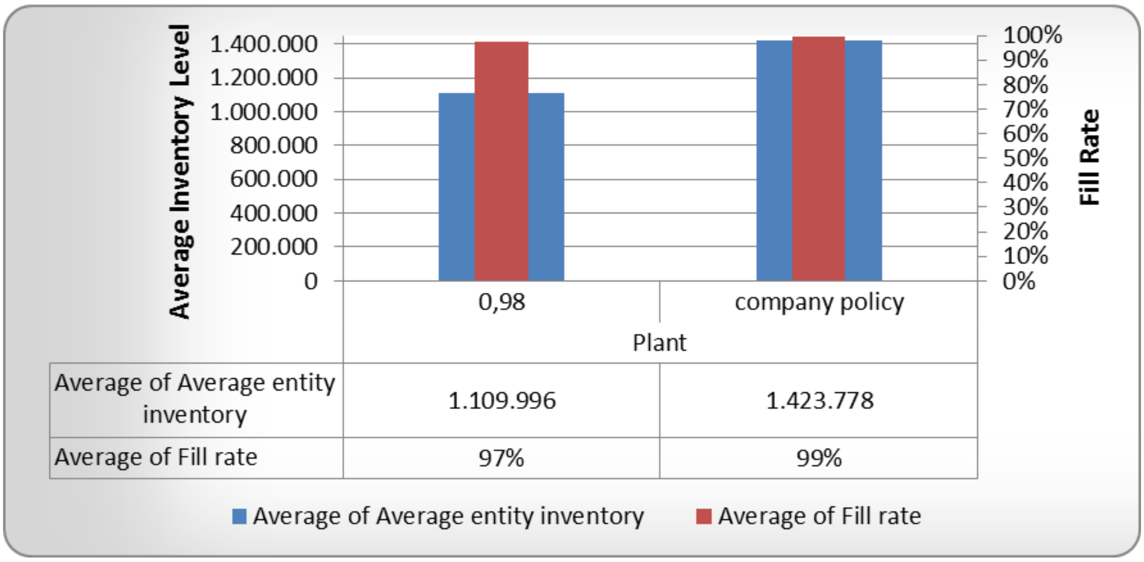
Figure 5.2: Total Ordering Cost and Average Inventory Level Comparison under Different Service Levels for No Hub, Medium Demand and 10% Standard Deviation Scenario / Million / $



Plant	0,9	0,98	company policy
Average of Inventory holding cost	1.573.932	1.596.233	2.331.783
Average of Back order cost	17.119.593	16.951.449	1.223.039

Figure 5.3: Backorder Cost and Inventory Holding Cost Comparison under Different Service Levels for No Hub, Medium Demand and 10% Standard Deviation Scenario / Million / $

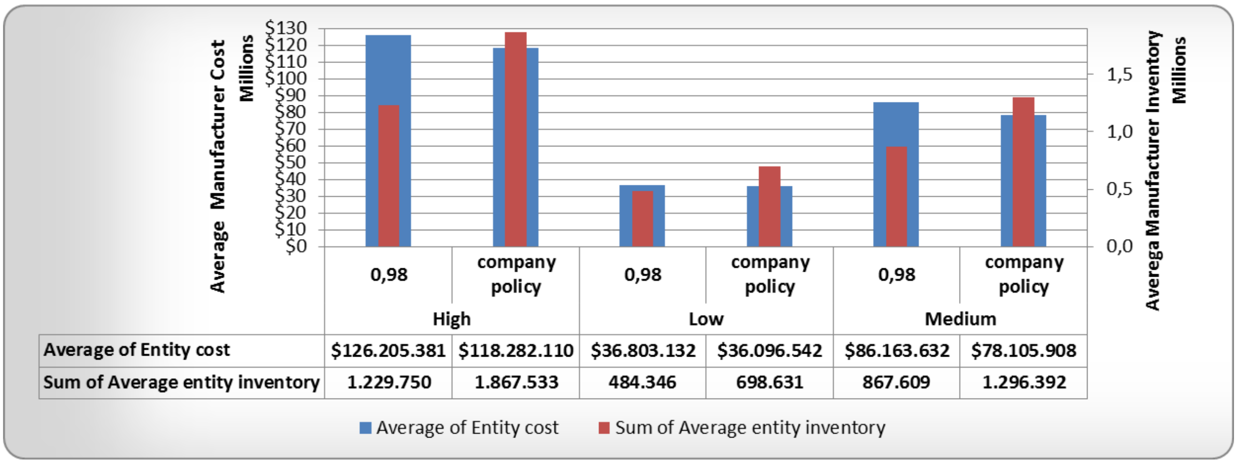
What is more, when the outputs of this current supply chain structure is analyzed it can be referred that since the backorder cost is quite higher compared to inventory holding cost nearly for all scenarios company policy gives the least total cost. Because, in company policy the inventory levels are significantly higher than the 90% and 98% service levels. On the other hand, if this model is applied to another company where the backorder cost and demand fill rate are not that much significant then below analysis illustrated with Figure 5.4 might demonstrate that although the fill rate does not decrease significantly there is a considerable amount of average inventory reduction if the service level has been changed as %98 service level where less ROP stock is kept compared to company policy. With the Figure 5.4 below it is observed that while average inventory level decreases about 22%, there is only 2% fill rate reduction from 99% to %97. Thus, although %98 or %90 service levels are not delivering good results for the company we are dealing with, ROP reduction polices may be quite attractive for some industries.



	0,98	company policy
Average of Average entity inventory	1.109.996	1.423.778
Average of Fill rate	97%	99%

Figure 5.4: Average Inventory Level and Fill Rate Comparison under 98% and Company Policy Service Levels for No Hub, Medium Demand and 60% Standard Deviation Scenario

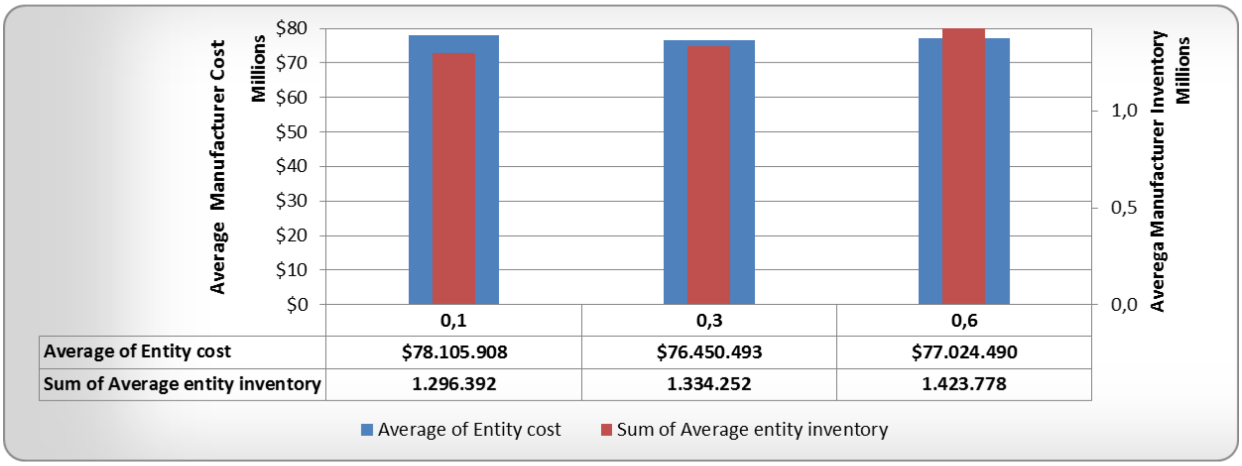
As it is mentioned before there are two more alternative for current procurement structure other than service level alternatives. These alternative scenarios are about demand and standard deviation rates. As it can be seen with below Figure 5.5 average manufacturer cost and inventory levels are fluctuating when demand rates change as high and low. As it is expected when the demand rate is low which is half of the medium demand manufacturer cost and inventory levels are decreasing. The situation is vice versa in high demand case where the demand is 50% more than the medıım demand.



	High 0,98	High company policy	Low 0,98	Low company policy	Medium 0,98	Medium company policy
Average of Entity cost	$126.205.381	$118.282.110	$36.803.132	$36.096.542	$86.163.632	$78.105.908
Sum of Average entity inventory	1.229.750	1.867.533	484.346	698.631	867.609	1.296.392

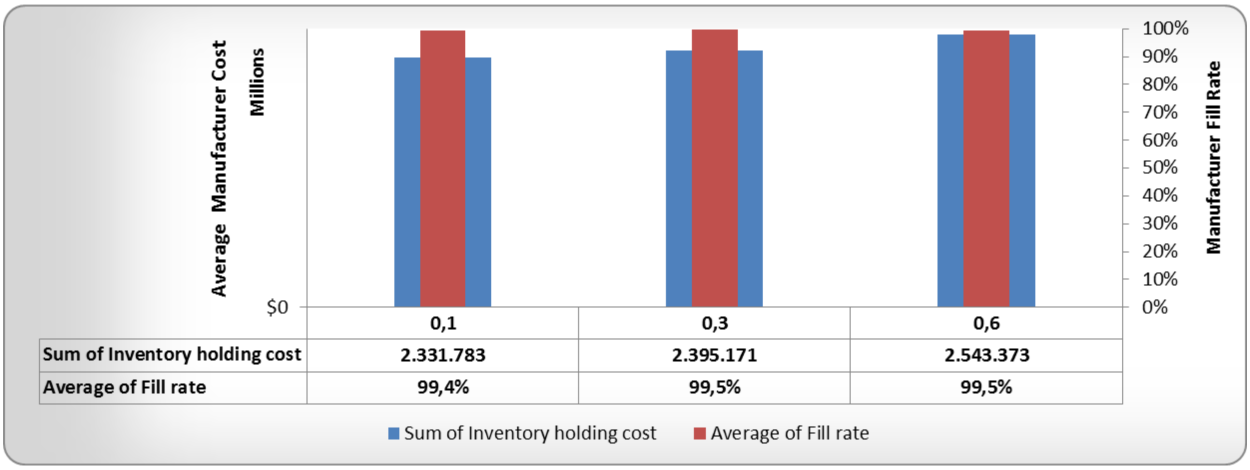
Figure 5.5: Total Cost and Average Inventory Levels of Manufacturers for Different Demand Rate Scenarios under No Hub, 10% Standard Deviation, Company Policy and 98% Service Level Case

The final scenario set which is standard deviation has also a similar impact as in the demand rate case. However, this time the changes are not significant rather they are a little. Please see below Figure 5.6 in order to observe total manufacturer cost and fill rates for different standard deviation ratios under medium demand, no hub and company policy service level case. Similarly, Figure 5.7 shows average inventory holding cost and fill rates of manufacturers under the same scenario. When these figure are analyzed it can be referred that standard deviation has not a big impact on the total manufacturer cost and fill rate whereas it increase average inventory level and inventory holding cost a little bit.



	0,1	0,3	0,6
Average of Entity cost	$78.105.908	$76.450.493	$77.024.490
Sum of Average entity inventory	1.296.392	1.334.252	1.423.778

Figure 5.6: Total Cost and Average Inventory Levels of Manufacturers for Different Standard Deviation Ratios under No Hub, Medium Demand and Company Policy Service Level Case



	0,1	0,3	0,6
Sum of Inventory holding cost	2.331.783	2.395.171	2.543.373
Average of Fill rate	99,4%	99,5%	99,5%

Figure 5.7: Average Inventory Holding Cost and Fill Rates of Manufacturers for Different Standard Deviation Ratios under No Hub, Medium Demand and Company Policy Service Level Case

5.3. Outputs of the Alternate Supply Chain Design (One Hub and Two Hubs Included Structure)

The same setup of traditional structure is also valid for this alternate supply chain designs' simulation models. The model is again run with various alternative scenarios (54 different scenarios) for 365 days as a run time with a warm up period of 365 days again. In terms of number of replication the model runs 10 times in order to provide a report. After running with a warm up period for each replication it creates a report in terms of the statistics we have require and write down some statistics for hub side in addition to existing manufacturers' statistics. These new statistics for hub side are total cost such as total custom cost, total ordering cost, average inventory level, fill rate and so on. These statistics are also kept for manufacturer side in this model in order to have a system wide cost details as a total. As a result, model provides output values of these statistics as an average of 10 replications. For the alternate business structure the model is run 54 times with different values for different scenarios. In terms of these scenarios we have determined four different scenario sets which are number of hubs included as a supply chain design, demand ratio as medium, low and high; standard deviation ratio as 10%, 30% and 60%; and finally service type as company policy, 90% and 98% service levels.

In terms of number of hubs alternatives there are two different scenarios which are 1 hub included and two hubs included structures. In these models the setting is exactly the same but all inputs as a data set has been altered in these setups.

In terms of demand rate, standard deviation and service level scenarios the setup used for current supply chain structure is also valid for this alternate design. Since all the scenarios are the same as in the current structure the only alteration in this alternate design is about the number of hubs included. Thus, in this new structure the number of alternate scenarios is 54 which is double of the number of alternatives in current setting.

Table 5.3 represents the output of the alternative scenarios in one hub included structure where the hub is located in Turkey while Table 5.4 shows the outputs of the two hubs included supply chain design where the first hub is located in Turkey and second hub is located in Dubai.

In terms of analysis of results, we did not run a comprehensive test of hypothesis but we represent sample results. Running a t-test for the difference of means of total ordering cost and fill rates with a confidence level of 95% we observe that there is not a statistically significant difference between total ordering cost and fill rate of one hub and without hub structures. However, we need to remark that the simulation system i.e Arena reports confidence interval level of 95% only. Therefore, based on the output figures it is likely that a statistically significant difference could be observed at a lower confidence interval. On the other hand, in terms of average inventory levels of manufacturers in one hub included and no hub included structures there is statistically significant difference according to 95% confidence interval output of Arena software.

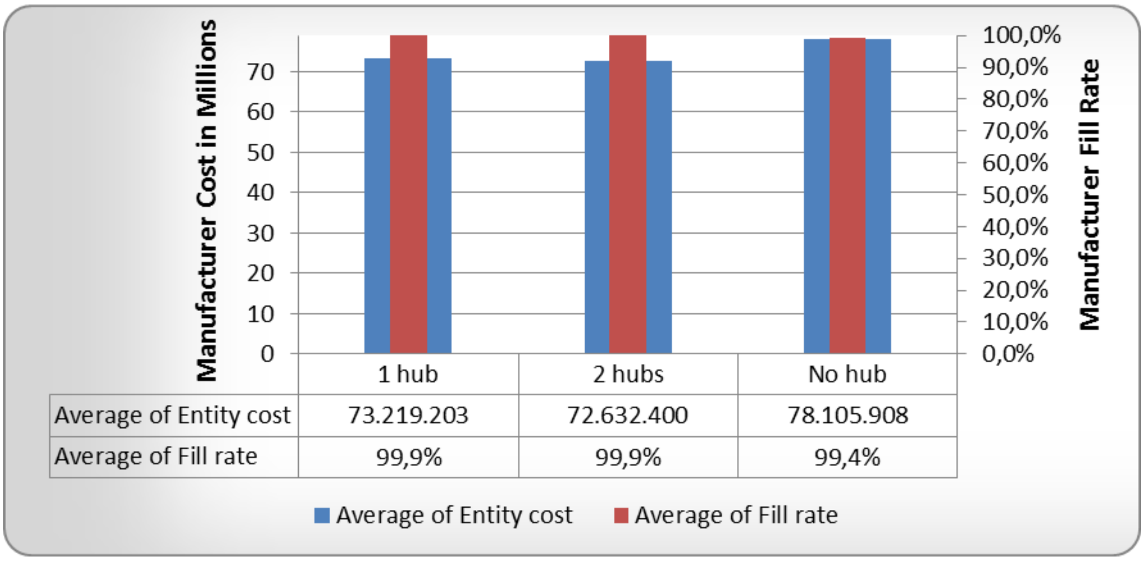
Table 5.3: Model Outputs for One Hub Scenario / Million / $

Alternative system	Number of hubs	Demand ratio	Standard deviation	Service type	Entity	Custom cost	Total ordering cost	Average inventory level	Average intransit level	Average supplier inventory	Average entity inventory	Inventory holding cost	Back order cost	Renting and operating cost of hub	Entity cost	Total cost	Fill rate
28	1 hub	Medium	0,1	0,9	Plant	8,8	56,3	0,37	0,22	0,00	0,59	1,0	13,5	-	79,5	95,1	93,9%
					Hub	8,6	4,6	0,45	0,25	0,09	0,70	1,3	-	1	15,5		
29	1 hub	Medium	0,3	0,9	Plant	8,9	56,8	0,41	0,23	0,00	0,65	1,1	9,3	-	76,1	92,3	95,7%
					Hub	8,8	5,0	0,54	0,26	0,10	0,80	1,5	-	1	16,2		
30	1 hub	Medium	0,6	0,9	Plant	9,2	58,3	0,49	0,24	0,00	0,73	1,2	7,4	-	76,1	92,9	96,6%
					Hub	9,1	5,2	0,61	0,28	0,10	0,89	1,6	-	1	16,9		
31	1 hub	Medium	0,1	0,98	Plant	8,8	56,6	0,39	0,23	0,00	0,62	1,0	11,7	-	78,2	93,8	94,6%
					Hub	8,7	4,7	0,44	0,27	0,10	0,70	1,3	-	1	15,7		
32	1 hub	Medium	0,3	0,98	Plant	9,2	58,7	0,45	0,23	0,00	0,68	1,1	7,5	-	76,5	93,1	96,6%
					Hub	9,0	5,2	0,50	0,27	0,10	0,77	1,4	-	1	16,6		
33	1 hub	Medium	0,6	0,98	Plant	9,4	59,9	0,56	0,25	0,00	0,81	1,4	4,0	-	74,7	92,0	98,1%
					Hub	9,3	5,4	0,60	0,30	0,10	0,90	1,7	-	1	17,3		
34	1 hub	Medium	0,1	company policy	Plant	9,7	61,5	0,83	0,25	0,00	1,07	1,8	0,3	-	73,2	91,2	99,9%
					Hub	9,6	5,3	0,87	0,30	0,11	1,17	2,1	-	1	18,0		
35	1 hub	Medium	0,3	company policy	Plant	9,9	62,9	0,85	0,25	0,00	1,10	1,8	0,5	-	75,2	94,3	99,8%
					Hub	9,8	6,1	0,89	0,30	0,11	1,19	2,2	-	1	19,0		
36	1 hub	Medium	0,6	company policy	Plant	10,0	64,1	0,91	0,26	0,00	1,17	1,9	0,5	-	76,5	96,2	99,8%
					Hub	9,9	6,5	0,95	0,31	0,11	1,26	2,3	-	1	19,7		
37	1 hub	High	0,1	0,9	Plant	12,8	83,5	0,51	0,33	0,00	0,83	1,4	21,9	-	119,6	143,1	93,2%
					Hub	12,7	8,1	0,60	0,37	0,14	0,97	1,8	-	1	23,6		
38	1 hub	High	0,3	0,9	Plant	13,4	87,0	0,56	0,34	0,00	0,91	1,5	15,9	-	117,7	142,8	95,1%
					Hub	13,3	8,7	0,70	0,40	0,15	1,09	2,1	-	1	25,1		
39	1 hub	High	0,6	0,9	Plant	13,8	89,8	0,68	0,35	0,00	1,03	1,7	13,1	-	118,4	145,0	96,0%
					Hub	13,7	9,5	0,84	0,43	0,15	1,27	2,4	-	1	26,6		
40	1 hub	High	0,1	0,98	Plant	13,0	85,0	0,51	0,34	0,00	0,86	1,4	18,6	-	118,1	142,2	94,2%
					Hub	12,8	8,5	0,56	0,39	0,14	0,95	1,8	-	1	24,1		
41	1 hub	High	0,3	0,98	Plant	13,7	89,2	0,63	0,35	0,00	0,98	1,6	14,0	-	118,5	144,4	95,7%
					Hub	13,5	9,5	0,62	0,40	0,15	1,02	1,9	-	1	25,9		
42	1 hub	High	0,6	0,98	Plant	14,3	92,9	0,79	0,36	0,00	1,15	1,9	7,6	-	116,7	144,2	97,7%
					Hub	14,2	10,0	0,82	0,41	0,15	1,23	2,3	-	1	27,5		
43	1 hub	High	0,1	company policy	Plant	14,2	92,4	1,16	0,37	0,00	1,53	2,5	0,6	-	109,8	138,5	99,8%
					Hub	14,2	10,5	1,22	0,43	0,16	1,65	3,0	-	1	28,7		
44	1 hub	High	0,3	company policy	Plant	14,7	95,2	1,21	0,37	0,00	1,58	2,6	0,5	-	113,0	142,4	99,8%
					Hub	14,5	10,9	1,23	0,44	0,16	1,67	3,0	-	1	29,4		
45	1 hub	High	0,6	company policy	Plant	14,3	93,3	1,30	0,36	0,00	1,66	2,8	0,6	-	111,0	139,8	99,8%
					Hub	14,3	10,3	1,35	0,43	0,15	1,78	3,2	-	1	28,8		
46	1 hub	Low	0,1	0,9	Plant	4,4	27,3	0,24	0,11	0,00	0,35	0,6	4,8	-	37,1	44,8	95,5%
					Hub	4,3	1,7	0,30	0,12	0,05	0,42	0,8	-	1	7,7		
47	1 hub	Low	0,3	0,9	Plant	4,5	28,1	0,25	0,12	0,00	0,38	0,6	3,7	-	36,9	44,9	96,6%
					Hub	4,4	1,8	0,32	0,14	0,05	0,46	0,8	-	1	8,0		
48	1 hub	Low	0,6	0,9	Plant	4,5	28,2	0,29	0,12	0,00	0,41	0,7	2,3	-	35,8	43,9	97,8%
					Hub	4,4	1,8	0,37	0,13	0,05	0,50	0,9	-	1	8,1		
49	1 hub	Low	0,1	0,98	Plant	4,5	28,1	0,25	0,12	0,00	0,36	0,6	4,2	-	37,4	45,3	96,1%
					Hub	4,4	1,8	0,29	0,14	0,05	0,42	0,8	-	1	7,9		
50	1 hub	Low	0,3	0,98	Plant	4,5	28,2	0,28	0,12	0,00	0,39	0,7	2,5	-	35,9	43,9	97,7%
					Hub	4,4	1,8	0,32	0,14	0,05	0,45	0,8	-	1	8,0		
51	1 hub	Low	0,6	0,98	Plant	4,7	29,3	0,33	0,12	0,00	0,46	0,8	1,4	-	36,1	44,7	98,7%
					Hub	4,6	2,0	0,36	0,14	0,05	0,50	0,9	-	1	8,6		
52	1 hub	Low	0,1	company policy	Plant	4,8	29,5	0,46	0,13	0,00	0,59	1,0	0,1	-	35,4	44,3	99,9%
					Hub	4,6	2,1	0,47	0,15	0,05	0,63	1,1	-	1	8,9		
53	1 hub	Low	0,3	company policy	Plant	4,6	28,8	0,48	0,12	0,00	0,61	1,0	0,1	-	34,6	43,2	99,9%
					Hub	4,5	1,9	0,50	0,14	0,05	0,65	1,2	-	1	8,6		
54	1 hub	Low	0,6	company policy	Plant	4,7	29,3	0,50	0,13	0,00	0,63	1,0	0,2	-	35,2	44,1	99,9%
					Hub	4,6	2,1	0,53	0,15	0,05	0,68	1,2	-	1	8,9		

Table 5.4: Model Outputs for Two Hubs Scenario / Million / $

Alternative system	Number of hubs	Demand ratio	Standard deviation	Service type	Entity	Custom cost	Total ordering cost	Average inventory level	Average intransit level	Average supplier inventory	Average entity inventory	Inventory holding cost	Back order cost	Renting and operating cost of hub	Entity cost	Total cost	Fill rate
55	2 hubs	Medium	0,1	0,9	Plant	8,7	55,3	0,36	0,23	0,00	0,59	1,0	12,7	-	77,7	93,6	94,3%
					Hub	8,6	4,3	0,43	0,26	0,10	0,69	1,0	-	2	15,9		
56	2 hubs	Medium	0,3	0,9	Plant	9,0	56,4	0,42	0,23	0,00	0,65	1,1	10,0	-	76,4	92,8	95,4%
					Hub	8,8	4,5	0,50	0,26	0,10	0,76	1,1	-	2	16,4		
57	2 hubs	Medium	0,6	0,9	Plant	8,9	55,8	0,49	0,23	0,00	0,72	1,2	8,5	-	74,5	91,2	96,1%
					Hub	8,8	4,7	0,62	0,27	0,09	0,89	1,3	-	2	16,8		
58	2 hubs	Medium	0,1	0,98	Plant	8,9	56,2	0,38	0,23	0,00	0,61	1,0	14,3	-	80,4	96,5	93,7%
					Hub	8,7	4,5	0,44	0,25	0,09	0,70	1,0	-	2	16,2		
59	2 hubs	Medium	0,3	0,98	Plant	9,2	57,8	0,45	0,24	0,00	0,69	1,1	8,3	-	76,5	93,6	96,2%
					Hub	9,1	5,0	0,49	0,25	0,10	0,75	1,1	-	2	17,2		
60	2 hubs	Medium	0,6	0,98	Plant	9,7	60,5	0,56	0,25	0,00	0,81	1,4	4,8	-	76,3	94,7	97,9%
					Hub	9,6	5,5	0,60	0,26	0,10	0,86	1,3	-	2	18,4		
61	2 hubs	Medium	0,1	company policy	Plant	9,7	60,8	0,81	0,26	0,00	1,07	1,8	0,3	-	72,6	91,7	99,9%
					Hub	9,6	5,8	0,82	0,29	0,11	1,10	1,6	-	2	19,0		
62	2 hubs	Medium	0,3	company policy	Plant	9,7	60,7	0,84	0,25	0,00	1,10	1,8	0,4	-	72,6	91,7	99,8%
					Hub	9,6	5,8	0,89	0,30	0,10	1,19	1,7	-	2	19,1		
63	2 hubs	Medium	0,6	company policy	Plant	9,9	62,1	0,91	0,25	0,00	1,16	1,9	0,2	-	74,1	93,6	99,9%
					Hub	9,8	5,8	0,93	0,29	0,10	1,22	1,8	-	2	19,5		
64	2 hubs	High	0,1	0,9	Plant	12,6	81,2	0,48	0,34	0,00	0,82	1,4	22,2	-	117,4	140,9	93,1%
					Hub	12,4	7,8	0,55	0,40	0,14	0,94	1,3	-	2	23,5		
65	2 hubs	High	0,3	0,9	Plant	13,3	85,1	0,56	0,35	0,00	0,91	1,5	19,9	-	119,8	145,3	94,1%
					Hub	13,2	8,8	0,68	0,40	0,14	1,09	1,5	-	2	25,5		
66	2 hubs	High	0,6	0,9	Plant	13,8	88,1	0,66	0,37	0,00	1,03	1,7	13,8	-	117,4	144,4	95,9%
					Hub	13,7	9,4	0,82	0,42	0,16	1,23	1,8	-	2	26,9		
67	2 hubs	High	0,1	0,98	Plant	13,1	83,5	0,50	0,35	0,00	0,85	1,4	22,0	-	120,0	144,6	93,3%
					Hub	13,0	8,2	0,59	0,40	0,15	0,99	1,4	-	2	24,6		
68	2 hubs	High	0,3	0,98	Plant	13,3	84,7	0,63	0,35	0,00	0,98	1,6	14,2	-	113,7	139,1	95,6%
					Hub	13,2	8,7	0,67	0,38	0,14	1,05	1,5	-	2	25,4		
69	2 hubs	High	0,6	0,98	Plant	14,0	89,0	0,78	0,37	0,00	1,15	1,9	7,3	-	112,2	138,9	97,8%
					Hub	13,9	9,1	0,83	0,39	0,15	1,22	1,8	-	2	26,7		
70	2 hubs	High	0,1	company policy	Plant	14,2	90,1	1,13	0,39	0,00	1,53	2,5	0,5	-	107,4	135,9	99,8%
					Hub	14,1	10,1	1,18	0,42	0,16	1,60	2,4	-	2	28,5		
71	2 hubs	High	0,3	company policy	Plant	14,8	93,5	1,21	0,37	0,00	1,58	2,6	0,6	-	111,6	141,2	99,8%
					Hub	14,7	10,4	1,27	0,43	0,15	1,70	2,5	-	2	29,6		
72	2 hubs	High	0,6	company policy	Plant	14,8	94,3	1,28	0,39	0,00	1,67	2,8	0,5	-	112,5	142,5	99,8%
					Hub	14,7	10,7	1,29	0,44	0,16	1,72	2,6	-	2	30,0		
73	2 hubs	Low	0,1	0,9	Plant	4,4	27,5	0,23	0,12	0,00	0,35	0,6	5,2	-	37,7	46,3	95,3%
					Hub	4,3	1,7	0,28	0,14	0,05	0,42	0,6	-	2	8,6		
74	2 hubs	Low	0,3	0,9	Plant	4,5	27,9	0,26	0,12	0,00	0,37	0,6	4,0	-	37,1	45,9	96,3%
					Hub	4,4	1,7	0,33	0,13	0,05	0,46	0,7	-	2	8,8		
75	2 hubs	Low	0,6	0,9	Plant	4,5	27,7	0,29	0,12	0,00	0,41	0,7	2,7	-	35,6	44,5	97,5%
					Hub	4,4	1,8	0,38	0,13	0,05	0,51	0,8	-	2	8,9		
76	2 hubs	Low	0,1	0,98	Plant	4,4	27,4	0,24	0,12	0,00	0,35	0,6	4,9	-	37,3	45,9	95,5%
					Hub	4,3	1,6	0,31	0,13	0,05	0,44	0,6	-	2	8,6		
77	2 hubs	Low	0,3	0,98	Plant	4,5	27,7	0,28	0,12	0,00	0,40	0,7	2,8	-	35,6	44,4	97,4%
					Hub	4,4	1,7	0,32	0,13	0,05	0,45	0,7	-	2	8,7		
78	2 hubs	Low	0,6	0,98	Plant	4,7	28,5	0,33	0,12	0,00	0,45	0,7	1,5	-	35,5	44,6	98,6%
					Hub	4,6	1,8	0,39	0,13	0,05	0,52	0,8	-	2	9,2		
79	2 hubs	Low	0,1	company policy	Plant	4,9	29,8	0,45	0,13	0,00	0,58	1,0	0,2	-	35,8	45,5	99,8%
					Hub	4,7	2,0	0,48	0,14	0,06	0,62	0,9	-	2	9,7		
80	2 hubs	Low	0,3	company policy	Plant	4,9	30,1	0,47	0,13	0,00	0,60	1,0	0,2	-	36,2	46,2	99,8%
					Hub	4,8	2,2	0,51	0,15	0,05	0,66	1,0	-	2	10,0		
81	2 hubs	Low	0,6	company policy	Plant	4,8	29,3	0,50	0,13	0,00	0,63	1,0	0,2	-	35,3	44,9	99,9%
					Hub	4,7	1,9	0,54	0,14	0,05	0,68	1,0	-	2	9,6		

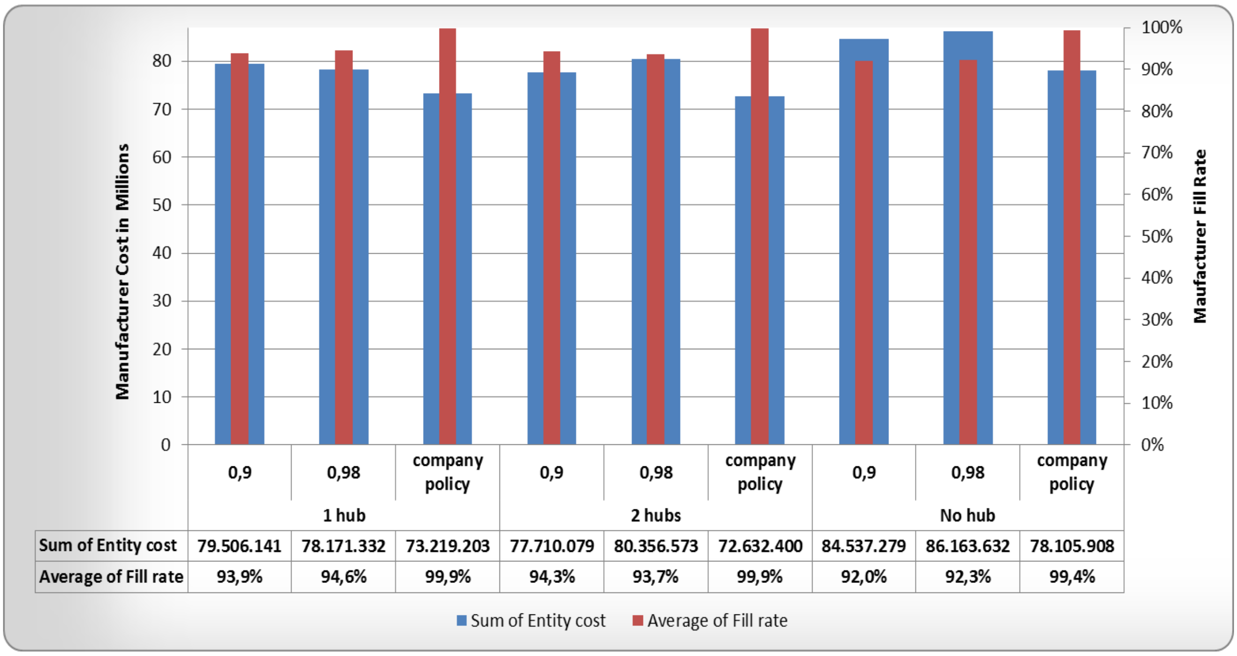
When the output of this alternate design is analyzed it can be clearly observed that with the introduction of hub as an alternate supply chain design the fill rates are having higher percentages while total cost are decreasing for the manufacturer side. Please see Figure 5.8 where a sample illustration about total cost and fill rate calculations on the manufacturer side under the medium demand, 10% standard deviation and company policy scenario. When this figure is analyzed, It can be observed that there is about7% total cost reduction in manufacturer side which is equal to 5,5 million USD dollars annually. On the other side the fill rate of manufacturers are also improved about %0,5 from 99,4% to 99,9% within the same scenario.



	1 hub	2 hubs	No hub
Average of Entity cost	73.219.203	72.632.400	78.105.908
Average of Fill rate	99,9%	99,9%	99,4%

Figure 5.8: Annual Total Cost and Fill Rate of Manufacturers under Medium Demand, Company Policy Service Level and 10% Standard Deviation for No Hub, 1 Hub and 2 Hubs Scenarios / $

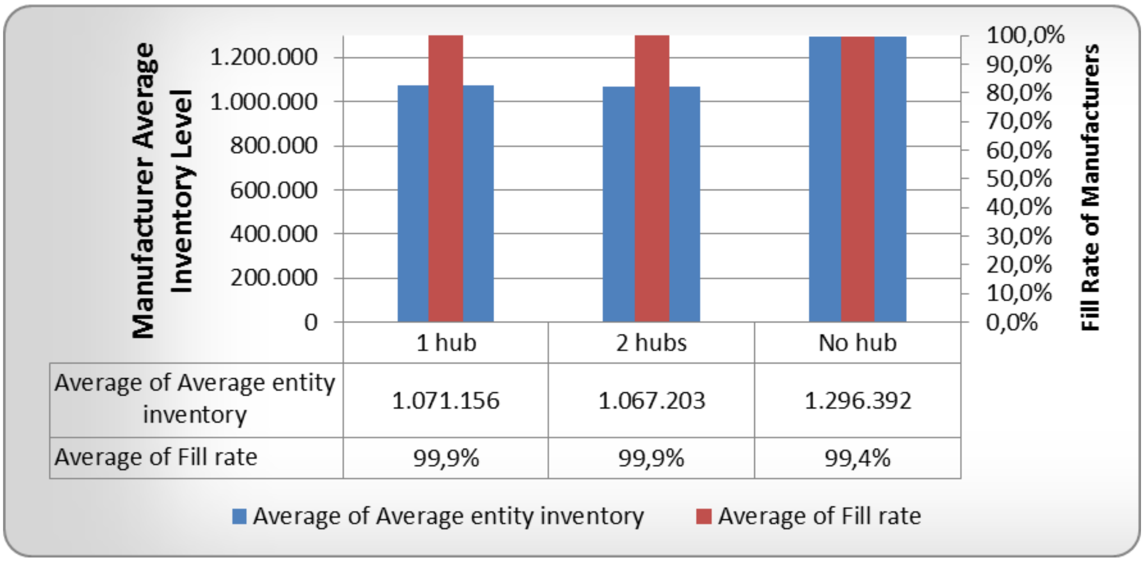
In the meantime, these results are showing the same response when service levels change as 90% and 98% as shown in Figure 5.9. However while 2 hubs included scenarios gives the best result in terms of total entity cost and fill rate under company policy and 90% service levels the situation alters in 98% service level towards the one hub included structure. As it can be observed from below figure one hub included structure gives the least total cost and highest fill rate under 98% service level where ROP levels are less than company policy. In addition to cost reduction, there is also a fill rate improvement for all service levels in hub included structure. This fill rate improvement is better than company policy service level in 90% and 98% service levels.



	1 hub			2 hubs			No hub		
	0,9	0,98	company policy	0,9	0,98	company policy	0,9	0,98	company policy
Sum of Entity cost	79.506.141	78.171.332	73.219.203	77.710.079	80.356.573	72.632.400	84.537.279	86.163.632	78.105.908
Average of Fill rate	93,9%	94,6%	99,9%	94,3%	93,7%	99,9%	92,0%	92,3%	99,4%

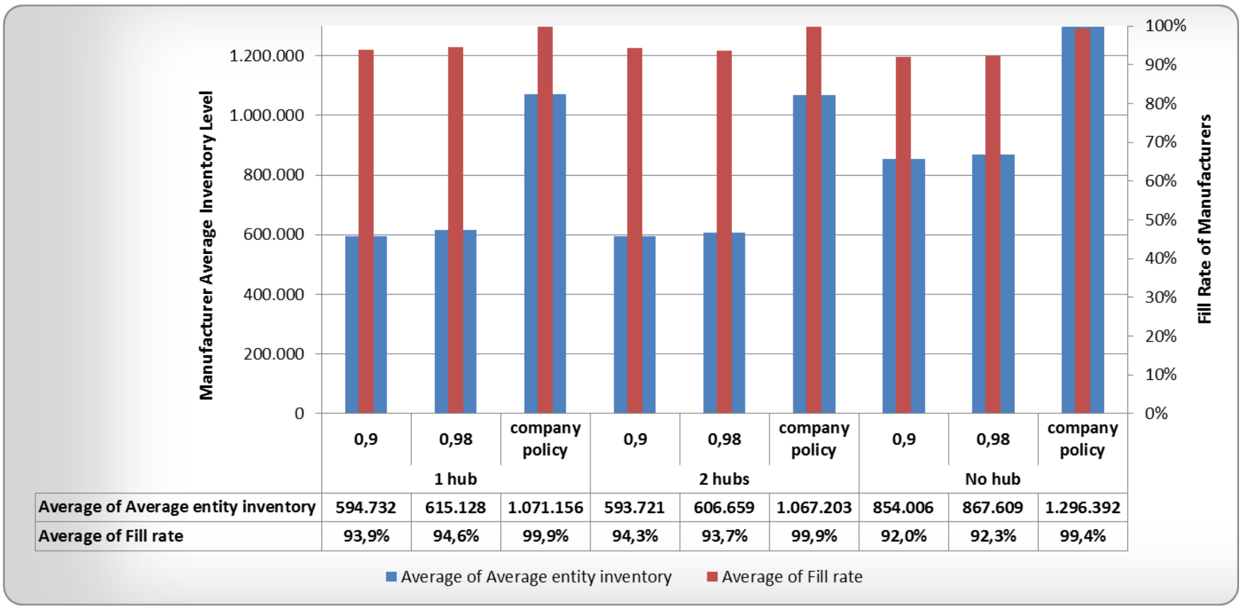
Figure 5.9: Annual Total Cost and Fill Rate of Manufacturers under Medium Demand, and 10% Standard Deviation for No Hub, 1 Hub and 2 Hubs Scenarios and Different Service Levels Scenarios / $

Furthermore, another vital figure for the company policy service level is that fill rate is a little bit improved as discussed before with the introduction of hubs although the average inventory levels of manufacturers decreases. The details of this argument are shown in Table 5.10. This is one of the significant outputs of this alternate supply chain design due to achieving a better fill rate although keeping fewer inventories for the manufacturer side. Similar to total cost comparison, the trends are also valid for 90% and 98% service levels as shown in Figure 5.11. When this figure is analyzed it can be understood that average inventory levels are in a decreasing trend with the decrease of ROP levels which are defined according to three different service level strategies.



	1 hub	2 hubs	No hub
Average of Average entity inventory	1.071.156	1.067.203	1.296.392
Average of Fill rate	99,9%	99,9%	99,4%

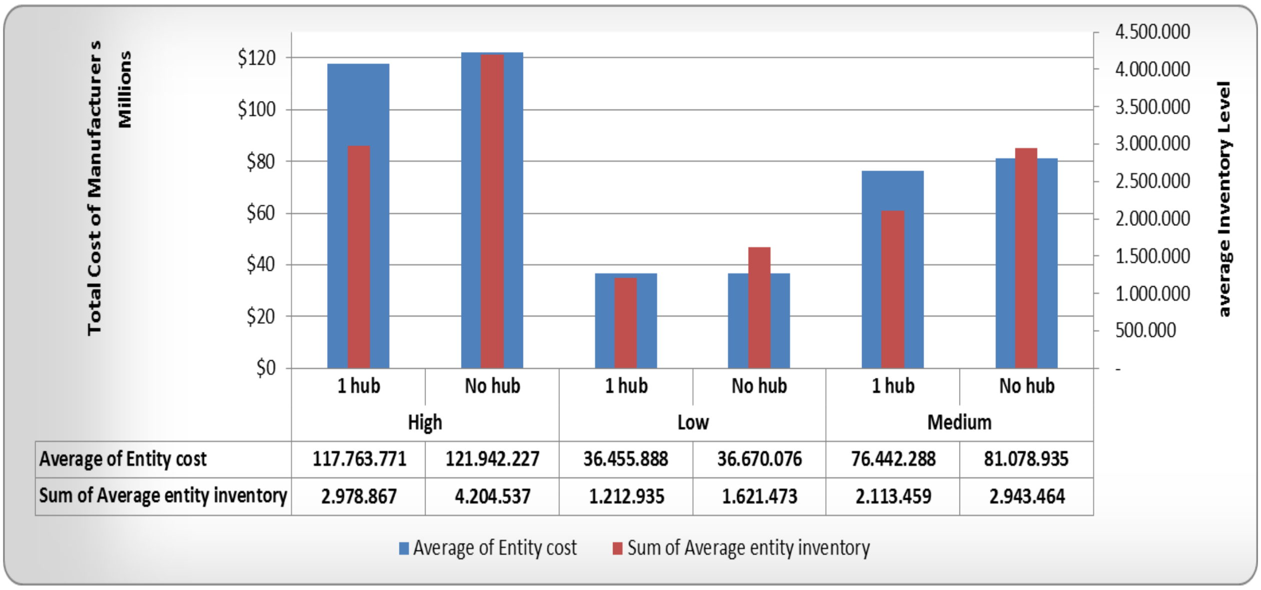
Figure 5.10: Average Inventory Level versus Fill Rate under Medium Demand, Company Policy Service Level and 10% Standard Deviation for No Hub, 1 Hub and 2 Hubs Scenarios



	0,9	0,98	company policy	0,9	0,98	company policy	0,9	0,98	company policy
	1 hub			2 hubs			No hub		
Average of Average entity inventory	594.732	615.128	1.071.156	593.721	606.659	1.067.203	854.006	867.609	1.296.392
Average of Fill rate	93,9%	94,6%	99,9%	94,3%	93,7%	99,9%	92,0%	92,3%	99,4%

Figure 5.11: Average Inventory Level versus Fill Rate under Medium Demand and 10% Standard Deviation for No Hub, 1 Hub and 2 Hubs and Different Service Levels Scenarios

In addition to these figure, Figure 5.12 below shows how total cost and average inventory levels of manufacturers are reacting according to different demand rates (low, medium and high) under 98% service level and 10% standard deviation for no hub and 1 hub included structures. Similarly, Figure 5.13 represents the how total cost and average inventory levels of manufacturers are reacting according to different standard deviation ratios (10%, 30% and 60%) under 98% service level and medium demand for no hub and 1 hub included structures. As it can be understand from these figures, average inventory levels are increasing when demand and standard deviation ratios are getting higher ratios. Similarly, total cost is also increasing when the demand rate is high and it is decreasing when the demand rate is lower. However, there is no correlation between total cost of manufacturer and standard deviation ratios. The reason is that, ROP levels are determined according to standard deviation ratios and for this reason fill rates are not decreasing when the standard deviation ratio is high. Since backorder cost is directly calculated by using fill rates and one of the main components of total cost is also back order cost the impact of standard deviation on total cost is so limited. Figure 5.14 indicates the sensitivity of fill rate towards standard deviation.



	High		Low		Medium	
	1 hub	No hub	1 hub	No hub	1 hub	No hub
Average of Entity cost	117.763.771	121.942.227	36.455.888	36.670.076	76.442.288	81.078.935
Sum of Average entity inventory	2.978.867	4.204.537	1.212.935	1.621.473	2.113.459	2.943.464

Figure 5.12: Total Cost and Average Inventory Levels of Manufacturers for Different Demand Rate Scenarios under 98% Service Level and 10% standard Deviation Case

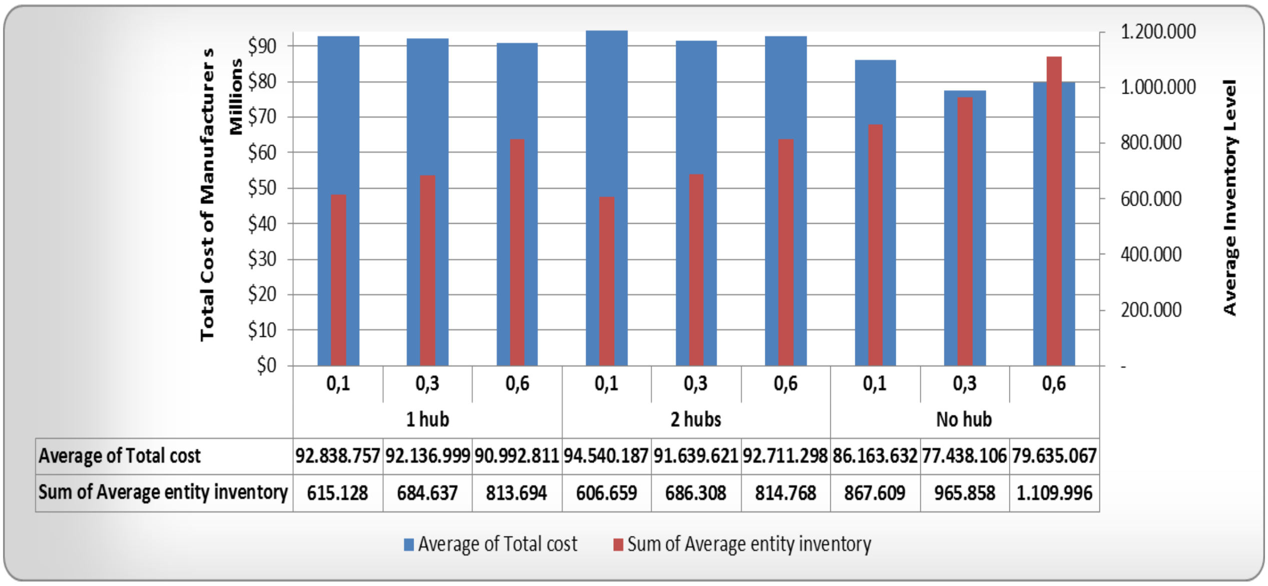


Figure 5.13: Total Cost and Average Inventory Levels of Manufacturers for Different Standard Deviation Ratios under Medium Demand, 98% Service Level, and All Supply Chain Structures

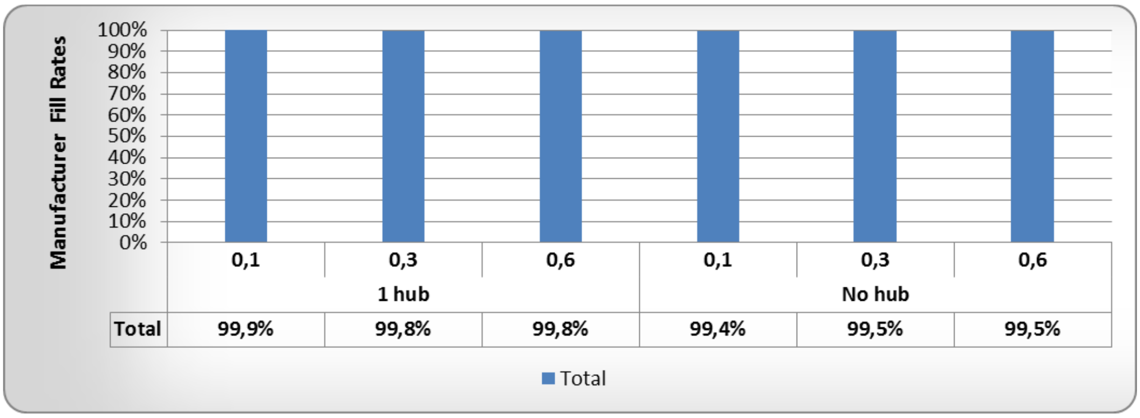
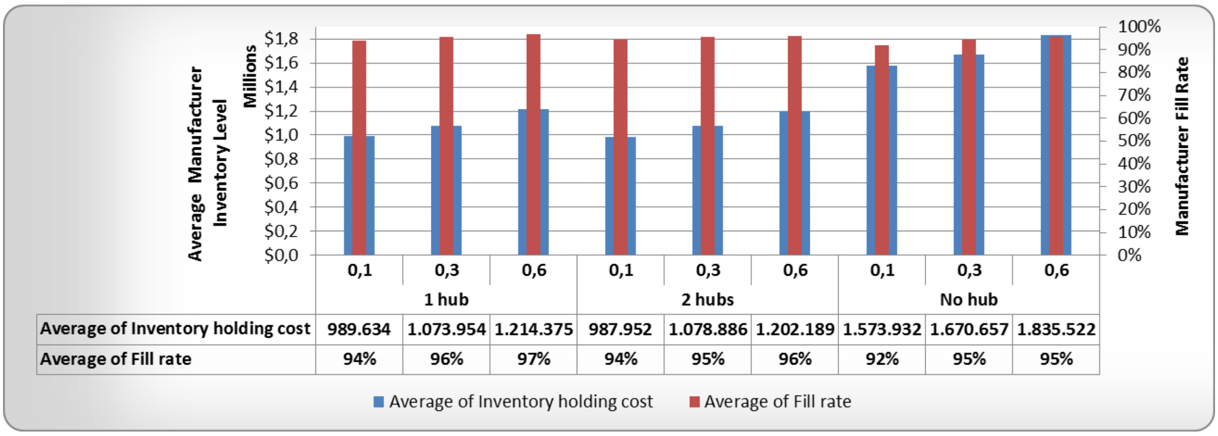


Figure 5.14: Fill Rates of Manufacturers for Different Standard Deviation Ratios under Medium Demand, Company Policy Service Level for No Hub and One Hub Included Structures

If we analyses all figures illustrated in this output section it so clear that manufacturers will have a saving opportunity in terms of total cost which is composed of purchasing, transportation, ordering, custom related, inventory holding and backorder costs.

Similarly, with the introduction of hubs the fill rates are enhanced while average inventory levels are decreasing compared to no hub structure (current company case) as it can be observed from Figure 5.15.



	1 hub			2 hubs			No hub		
	0,1	0,3	0,6	0,1	0,3	0,6	0,1	0,3	0,6
Average of Inventory holding cost	989.634	1.073.954	1.214.375	987.952	1.078.886	1.202.189	1.573.932	1.670.657	1.835.522
Average of Fill rate	94%	96%	97%	94%	95%	96%	92%	95%	95%

Figure 5.15 Fill Rate Trend with the Introduction of Hubs under Medium Demand, 90% Service Level and 10% Standard Deviation ratio Case

However, it is also necessary to observe the whole inbound supply chain cost where both manufacturer and hubs' total costs are compared. In terms of this comparison it is observed that total supply system cost are increasing considerable amount which is at least about 7% which is nearly equal to 6,6 million USD dollars. Below Figure 5.16 represent the comparison of total system cost for different supply chain designs and standard deviation ratios as 10%, 30% and 60% under medium demand and 98% service level. The same situation is also valid for other service types and demand ratios. Furthermore, when fill rates of manufacturers' on Figure 5.17 analyzed for different supply chain designs and service levels it is observed that although there is an improvement they are not that much vital which are between 0,4 and 1,5 percent.

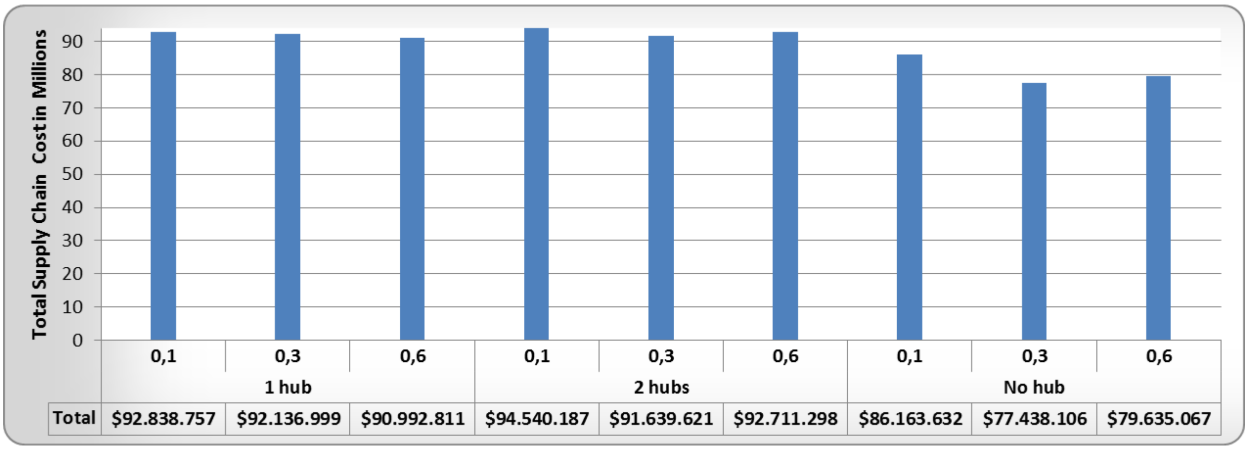


Figure 5.16: Total Supply Chain Cost under Medium Demand and 98% Service Level for No Hub, 1 Hub and 2 Hubs Included Supply Chain Designs with Different Standard Deviation Ratios

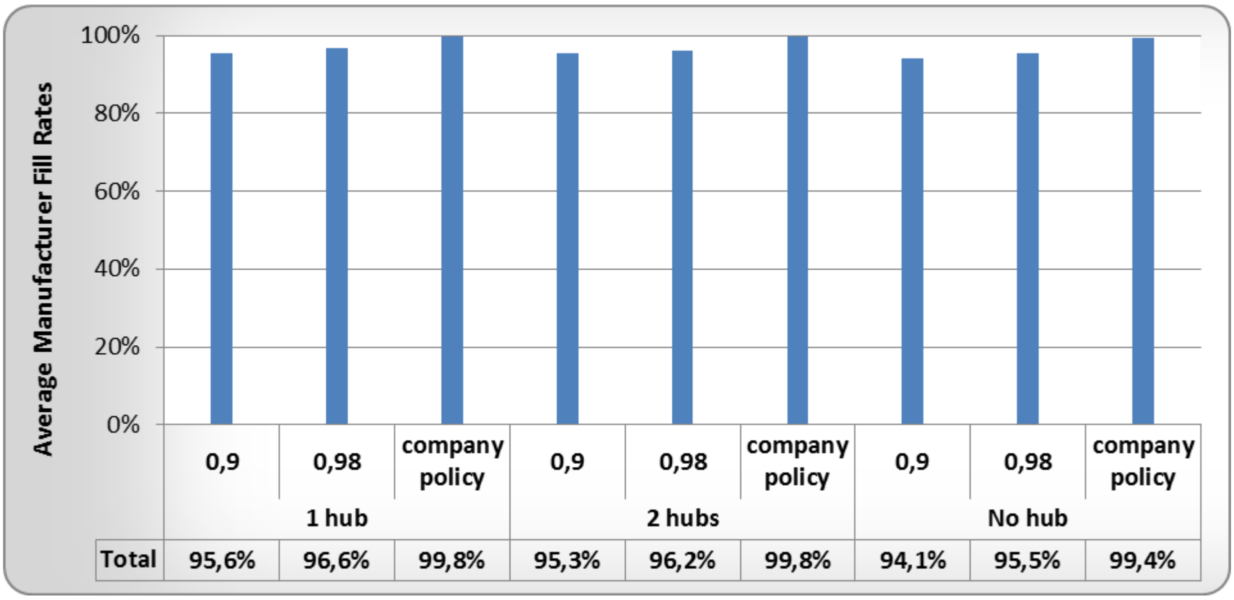


Figure 5.17: Average Manufacturer Fill Rates for All Supply Chain Designs under Different Service Levels, Medium Demand and 10% Standard Deviation

After analyzing above figure and below Figure 5.18 it can be clearly referred that one hub and two hubs included scenarios have so similar cost under various service levels and standard deviations. However, two hubs included structure shows a better performance in terms of total cost under 90% and company policy service levels whereas 1 hub included structure delivering less total cost under 98% service level.

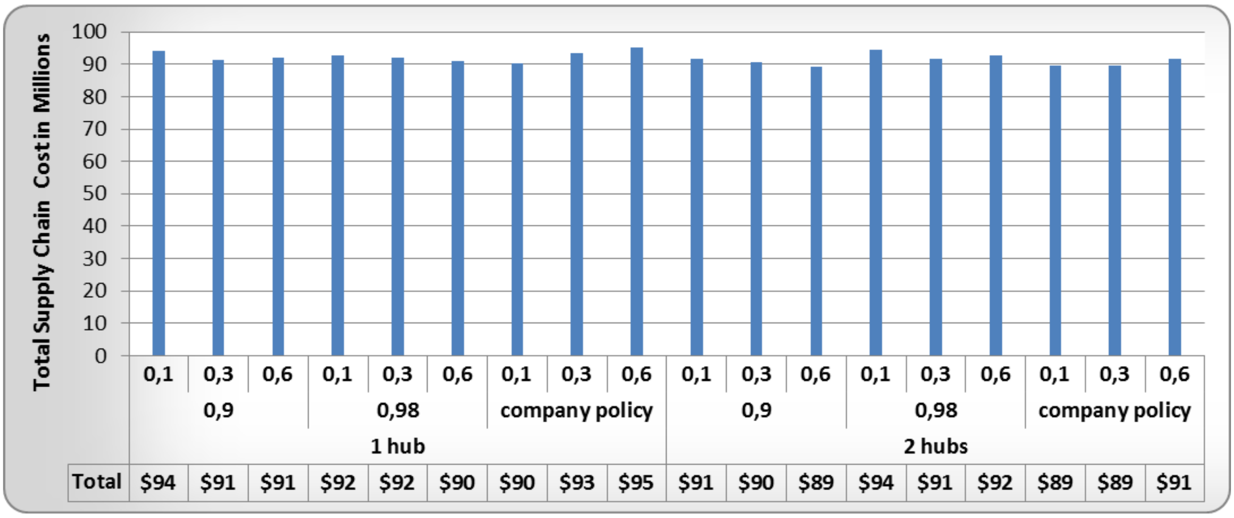


Figure 5.18: Total Supply Chain Cost under Medium Demand for 1 Hub and 2 Hubs Supply Chain Designs with Different Standard Deviation Ratios and Service Level

Although total cost of the system is increasing with the introduction of hubs pipeline inventory which represent the whole physical and in transit inventory on the manufacturer, hub and supplier side is decreasing a few percent as illustrated with Table 5.5 below. There is about 4% decreases in two hubs included structure. For the manufacturer side, as it is discussed before inventory levels are greatly decreased as about 30 percent.

Table 5.5: Pipeline Inventory Level Reduction

Supply Chain Structure	Entity	Physical Inventory	In transit ınventory	Supplier Inventory	Total Pipeline Inventory	Manufacturer Inventory Reduction	Pipeline Inventory Reduction	Fill Rate of Maunufacturer
No hub	Plant	798.550	497.842	734.440	2.030.832	0%	0%	99%
1 hub	Plant	668.151	240.573	106.018	1.974.487	30%	3%	99%
	Hub	681.295	278.449					
2 hubs	Plant	656.667	255.471	106269	1.957.331	30%	4%	99%
	Hub	658.506	280.419					

CHAPTER VI

CONCLUSION AND FURTHER RESEARCH

6.1 Conclusion

Companies performing in international platform face with a severe competition where there are various pressures such as uncertainties, competitors, operation wideness and different governmental regulations. Within this environment surviving in the market with an industrial growth is severe challenge. In order to survive in the market and have a success in terms of corporate goals customer satisfaction and coping with uncertainties are quite vital. Since one of the most important components of supply chain is the end user, the satisfaction of them plays a vital role through the destiny of companies. In order to satisfy these end users there are many different aspects such as price, quality, on time delivery, fill rate and so on. On the other side, uncertainty is one of the most severe challenge companies are facing within this global environment.

Throughout this thesis we focus on the logistics related customer satisfaction and total cost aspects under uncertain environment. In terms of fill rate we deal with a fill rate which simply means the percentage of satisfying the demand of customers from physical inventory. In terms of uncertainty we cover demand and lead time uncertainties. Through this manner we reevaluate common supply chain structure and then design alternative supply chain structure where supply hubs are located. In order to measure the effectiveness of this new supply chain design we collaborate with a Fortune 500 multinational company located in Turkey. We analyze the current supply chain design, all related operations and cost parameters that take part in this company’s structure.

Thereafter, a detailed literature review has been performed on the supply chain design and uncertainty. After these reviews simulation modelling method where coping with uncertainty and including detailed operation insights are easier has been chosen. After this step we start modeling and numerical study. By studying with industry advisors simulation model is validated and verified and then many different alternative data inputs and simulation models are created. These alternatives are about the demand rate, standard deviation, ROP level and different supply chain designs. By forming these alternative totally 81 different models has been created and run in order compare their results with each other and suggesting the best one.

When all model outputs are analyzed it is clear that company's current ROP levels are quite satisfactory in terms of fill rates. Similar to this logic, when the ROP amounts are decreased with 90% and 98% service levels, it is observed that fill rates are decreasing in a considerable amount. For this reason, it is fair to say that for the current supply chain structure, company follows a successful policy where stock out occurrence is rare. However, if this model is applied to another company which operates in a different sector where fill rates are not that much deadly, our 90% and 98% service level may give good results where fill rates decrease about 2 percent whereas there is about 20 percent holding inventory reduction.

In terms of the new supply chain design where 1 and 2 hubs are introduced there are also good results for the manufacturer sides. For these new supply chain designs, overall fill rates and total costs of manufacturers are improved considerably. Cost reduction on manufacturer side is about 7% while fill rate increase is between 0,5 and 3 percent. Moreover, there is a significant reduction in inventory level for manufacturer side. Thus, it is logical to say that manufacturers will prefer to have such a supply chain design where their costs are reduced about 7% and fill rates are improved.

On the other hand, if total supply chain cost of current and alternate structures are compared with each other, it can be observed that there is about at least 7% total operational cost increase which is quite considerable. The difference between two structures about total supply chain cost is about 10% when standard deviation is 30% and 60%. However, there are also advantageous sides of new structure. For example, manufacturers' fill rates are improved between 0,5 and 3 percent under different service levels. Furthermore, total pipeline inventory is reduced about 4 percent with the introduction two hubs included supply chain design.

As it is discussed before the ownership and management of supply hubs will be under the responsibility of suppliers. The reason of this aspect is that suppliers will not hold inventory in their current production facilities. Instead, significant part of their finished good stocks will be held in supply hubs. With this new structure they have quite lower inventory amount in their current facility and cost of holding this inventory will be decreased significantly. On the other side, this cost will switch to supply hub side. In addition to inventory issue another important aspect is other resources such as facility source, human resource and so on. In the same manner while these costs decrease on their current side, a new cost component will be valid in terms of supply hubs. However, since the cost of operating supply hubs will be divided into number of total suppliers, the whole cost would be shared by all suppliers. This may result in economies of scale in terms of inventory holding and order management cost components which are performed by different locations in the current business setting. Thus, operating a new entity for suppliers will not that much costly due to the current costly supply chain structure.

On the other side, suppliers will have some disadvantageous aspects such as cash flow and switching to new design which means creating completely new system from the beginning. However, since nowadays manufacturers are the customers of suppliers additional total supply chain cost that occurs with the introduction of hubs can be accepted by suppliers. Because, there will be also several advantageous sides for suppliers.

First of all, with the introduction of this structure suppliers will not hold inventory in their premises instead they will shipped all of their finished goods to their hubs. With this new design, supplier’s inventory holding cost may decrease. For example, they may hire their current depot to other companies or they may think about new investment alternatives by using their unused depot area.

Moreover, a mutual long term agreement may be the biggest advantage for suppliers. Because, nowadays companies are finding new suppliers in an easier way. Switching to another supplier is not a big severe for multinational companies if the quality and cost issues are suitable for the alternate supplier. For this reason, losing a customer for supplier side may be a huge loss. Thus, signing a long term contract with manufacturer may be a great chance for suppliers.

Another agreement between suppliers and manufacturers may be a markup price which can be added to the purchasing price of materials in order to share the cost and risk of new alternate supply chain design. A balanced agreement point can be determined in order to increase the performance of the whole supply chain in terms of service level and overall pipeline inventory level.

Due to these reasons, supplier may approach to this new alternate structure positively with a mutual agreement with manufacturers. However, switching to another design in supply chain is not that simple. It requires fully integration by using information technology and other resources effectively. But improving the whole structure can deserve some risks.

6.2 Further Research

We believe that this thesis is not only applicable to mentioned FMCG company but also other sectors and companies. Through this thesis the main strategic focus is design of a new supply chain structure under uncertainty. However, there are also other operational insights covered such as measuring the outcome of working with different ROP levels and measuring the effect of consolidation with the introduction of supply hubs. In addition to these insights, as a further study, another important consideration may be measuring the outcome of many different ROP stock levels and determining the best ROP levels under uncertain scenarios about demand and lead time.

The main uncertain parameter in this thesis is demand which includes both the uncertainty in demand itself (as low, medium and high demand scenarios) and the changes in standard deviations (10%, 30%, and 60% scenarios). We believe that these insights are fair enough for the applied sector and company but these scenarios can be extended while applying this simulation to other industries. The second uncertain parameter in the thesis is lead time however we have not included different scenarios on lead time distribution as it is the case in demand side. We take lead time as a normally distributed and a specific standard deviation (10%) for each scenario. For this reason, this thesis can be extended easily by including different lead time scenarios. Illustrating different outcomes with various lead time scenarios may be attractive and useful too.

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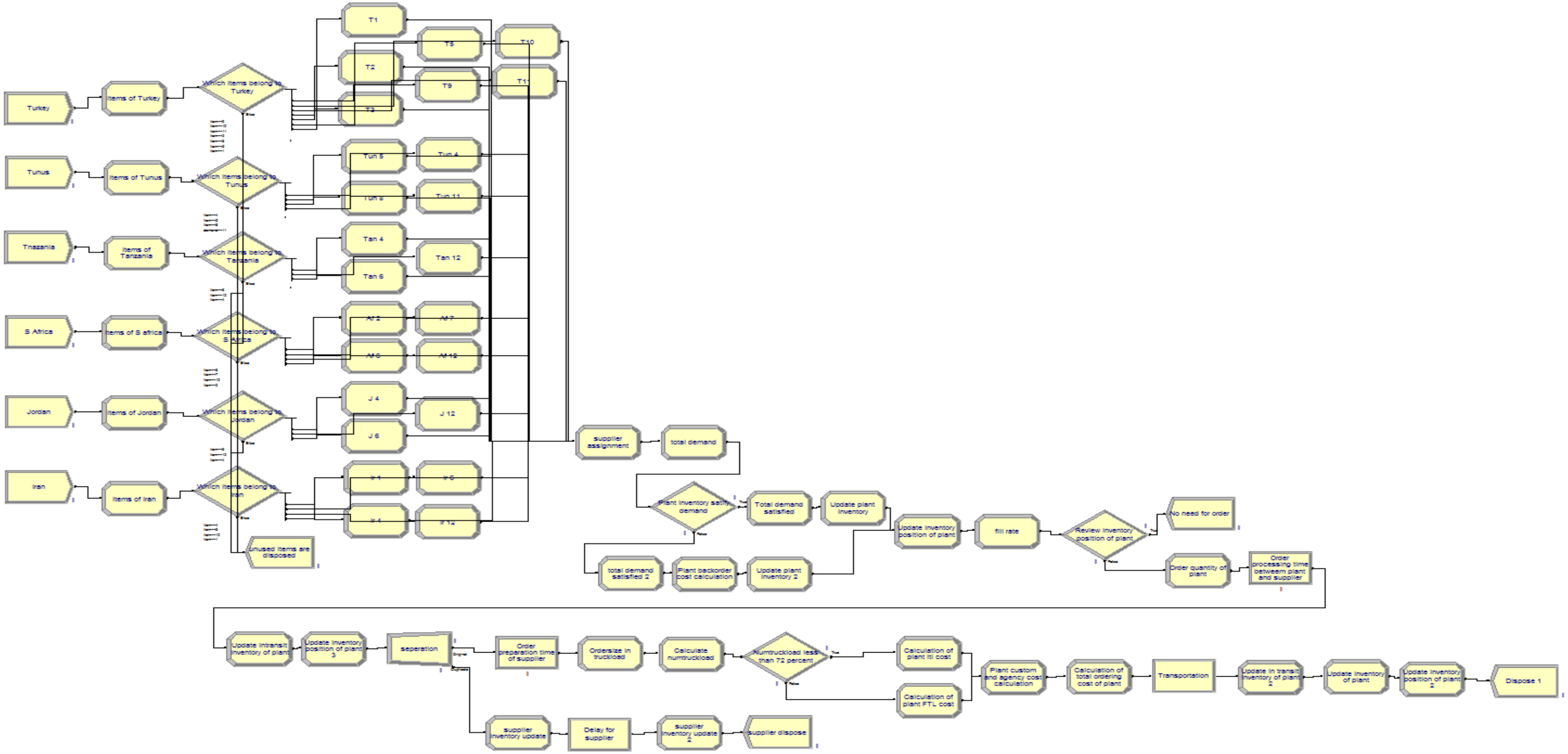
APPENDIX

Appendix - A. Arena Model for No Hub Structure



Appendix - B. Arena Model for Multiple Hub Structure