T.C. DOGUS UNIVERSITY
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PHD IN LOGISTICS AND SUPPLY CHAIN

SUPPLY CHAIN NETWORK OPTIMIZATION MODEL INCORPORATING COMPETITIVE FACILITY LOCATION PROBLEMS

by

CANSER BILIR
2010193006

ADVISOR:
ASSOC. PROF. DR. SULE ONSEL EKİCİ

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Dissertation of Canser Bilir

has been approved by

Assoc. Prof. Dr. Sule Onsel Ekici
(Advisor) ______________________________

Prof. Dr. Fusun Ulengin
(Committee Member) ______________________________

Prof. Dr. Orhan Feyzioglu
(External Committee Member) ______________________________

Assoc. Prof. Dr. Umut R. Tuzkaya
(External Committee Member) ______________________________

Assist. Prof. Dr. Peral Toktaş Palut
(Committee Member) ______________________________

Summary

The detailed literature review on SC network models showed that almost all of the SC network optimization models ignore the impacts of SC network decisions on the customer demand. However, the physical network structure of a SC is one of the important factors impacting chain's competitiveness, especially for the retail markets. On the other hand, competitive facility location problems model only distribution part of the SC even though they have some characteristics of SC networks and analyze the rival chains existing in the market.

In this dissertation study, a multi-objective SC network optimization model, incorporating competitive facility location models is developed. The objectives utilized in the model are; profit maximization, sales maximization and SC risk minimization.

The model is defined as Mixed Integer Linear Programming (MILP) model with three echelon SC network, with multi products, and single term. The SC structure consists of three echelons; Suppliers, Distribution Centers and Customer Zones. In order to simplify the model, products are aggregated to 10 different product types to represent the whole product mix. Nature of the developed model is deterministic. The unique unknown variable within the model is the demand. The demand at each customer zone is assumed to be determined by the price and the attraction function. Attraction Utility function is defined as the availability of same-day transportation from DC to Customer Zone.

The model is applied to a real life problem of one of the leading ready – wear clothing companies in Turkey. The company currently has only one DC in Istanbul. However, the number of sales points and the total sales volume of the company increased sharply, in recent years. It is considered that the firm needs to reconfigure its supply chain network and to decide whether or not to open additional Distribution Center(s) in alternative locations.

The model is first solved as a profit maximization problem. In the optimal solution for profit maximization problem, the sales decreased by 26 %. Because of the competition within the market, the 26 % sales decrease is not acceptable by any firms. Therefore, it has been concluded that modeling the problem as profit maximization does not generate required results and all three performance measures (profit, sales, risks) need to be taken into account.

Then, the model is solved as multi-objective with a goal programming method. The results proved that including attraction function on the model may change the performance results of the model and eventually SC network decisions. When the model moves from one DC (current situation) to two DCs, the model generates around 5 % more sales volume due to the defined attraction function. Without including attraction function impact on the model, one DC options are chosen. However, the model with the attraction function proposes DMs to utilize two DCs concurrently.

The result of this study contributes to the Supply Chain Network Optimization model literature mainly in two ways. First, the developed and analyzed model is the first SC network optimization model incorporating the changes in the demand, which is subject to the both price and distance from the end-customers and which is substantially influenced by strategic level SC network model decisions. Second, this model is also the first model simultaneously utilizing supply side risk analysis, demand functions and strategic level SC decisions. Developed model also proved that single objective models may not generate acceptable results and showed that SC network optimization models need to be defined as multi-objective since SCs are multi-objective in their nature.

Özet

Tedarik Zinciri (TZ) network modelleri üzerinde gerçekleştirilen detaylı literatür taraması göstermiştir ki, bu modellerde, TZ network kararlarının talep üzerindeki etkileri ihmal edilmiştir. Bununla birlikte, bir TZ'nin fiziksel network yapısı bir tedarik zincirinin rekabetçiliğini, özellikle perakende pazarlarda, etkileyen önemli unsurlardandır. Bunun yanında, "Rekabetçi Tesis Yeri Seçim Modelleri" ise her ne kadar TZ networklerinin bazı özelliklerini içerse ve pazardaki rekabet yapısını ele alsa da, TZ'lerinin sadece dağıtım kısımlarını modellemekte ve bir bütün TZ modeli sunmaktan uzaktırlar.

Literatürde yer alan bu açığı kapatmak amacı ile, bu doktora tezinde, TZ network optimizasyon modelleri ile rekabetçi tesis yeri seçimi modelini birleştiren çok amaçlı TZ network optimizasyon modeli geliştirilmiştir. Modelde kullanılan amaçlar; kar maksimizasyonu, satış maksimizasyonu ve TZ riskinin minimize edilmesidir.

Model, çok ürünlü ve tek dönemli, 3 aşamalı bir TZ olarak, Değişken Tamsayılı Lineer Programlama ile tanımlanmıştır. TZ'nde yer alan aşamalar şöyledir; Tedarikçiler, Dağıtımı Merkezleri ve Müşteri Bölgesidir. Modeldeki karmaşayı artırmamak adına, ürün gamı, tüm ürünleri temsil etmek üzere, 10 farklı ürün altında toplanmıştır. Model deterministik olarak tanımlanmıştır. Model içerisinde bilinmeyen tek değişken ise "talep"tir. Her bir müşteri bölgesindeki talebin fiyat ve çekicilik (fayda) fonksiyonunun bir bileşeni olduğu varsayılmıştır. Çekicilik fonksiyonu ise Dağıtım merkezi ile müşteri bölgesi arasında aynı gün içerisinde ürün tedariki yapılıp yapılamamasına göre tanımlanmıştır.

Model Türkiye'de var olan lider hazır giyim firmalarından bir tanesinin gerçek hayat problemine uygulanmıştır. Firma hâlihazırda İstanbul'da yer alan tek bir Dağıtım merkezine sahiptir. Bununla birlikte, firmanın satış noktaları ve toplam satış hacmi son yıllarda hızlı bir şekilde artmıştır. Firmanın, TZ networkunu yeniden tasarlaması ve mevcudun yanında bir veya daha fazla Dağıtım Merkezi açıp açmamayı değerlendirmesi gerektiği düşünülmektedir.

Model ilk olarak Kar Maksimizasyonu problemi olarak çözülmüştür. Bu problem için optimal çözüm noktasında satışların % 26 azaldığı görülmüştür. Pazarda var olan rekabet dolayısıyla % 26 satış azalması kabul edilebilir olarak görülmemektedir. Bu sebepledir ki, kar maksimizasyonu probleminin istenen sonuçları üretmeyeceği ve tüm performans ölçütlerinin (kar, satış hacmi ve risk) dikkate alınması gerektiği sonucuna varılmıştır.

Bundan sonra model "Amaç Programlama" yöntemi ile tekrar tanımlanmıştır. Bu model ile elde edilen sonuçlar göstermiştir ki, "Çekicilik Fonksiyonun" modelde kullanılmış olması modelin performans sonuçlarını ve dolayısıyla da TZ kararlarının değişmesine sebep olabilmektedir. Modelde tek bir Dağıtım Merkezinden, iki Dağıtım merkezli bir yapıya geçildiği zaman model "çekicilik fonksiyonu etkisi" sebebi ile yaklaşık olarak % 5 daha fazla satış elde edilmesini sağlamaktadır. Bu sebepledir ki "çekicilik fonksiyonu" etkisi olmaksızın kurulan modelde tek bir Dağıtım Merkezi önerilirken, "çekicilik fonksiyonu" eklendikten sonra, model iki Dağıtım Merkezi açılmasını önermektedir.

Bu çalışmanın sonuçları TZ network optimizasyon modellerine birçok açıdan katkı sağlamaktadır. İlk olarak, bu çalışmada yer alan model, fiyat ve nihai müşteriden uzaklığa bağlı olarak belirlenen ve TZ network kararlarından önemli oranda etkilenen talepteki değişiklikleri de içerisinde barındıran ilk TZ network modelidir. İkinci olarak ise bu çalışmada yer alan model tedarik risk analizini, talep fonksiyonunu ve stratejik düzeydeki TZ kararlarını aynı anda kullanan ilk modeldir. Burada geliştirilen model aynı zamanda, tek amaçlı modellerin nasıl istenen sonuçları sağlamadığını ve TZ'lerinin zaten doğası gereği olarak çok amaçlı olarak tanımlanması gerektiğini ortaya koyan bir çalışma olmuştur.

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Abbreviations

SC	Supply Chain
DC	Distribution Center
PC	Personal Computer
MIP	Mixed Integer Programming
GIS	Geographical Information System
NPV	Net Present Value
JIT	Just-in-Time
MP	Mathematical Programming
GA	Genetic Algorithm
KPI	Key Performance Indicators
MINLP	Mixed Integer Non-Linear Programming
PLP	Possibilistic Linear Programming
TFN	Triangular Fuzzy Numbers
LP	Linear Programming
SCNM	Supply Chain Network Modeling
WIP	Work-in-Process
LT	Lead Times
CSL	Customer Service Level
SKU	Stock Keeping Unit
DM	Decision Maker

CHAPTER 1. INTRODUCTION

A supply chain (SC) may be defined as an integrated effort where various entities (suppliers, manufacturers, distributors, and retailers) work together in order to: acquire raw materials, convert these materials into specified final products, and deliver these final products to the retailers. This chain is traditionally characterized by a forward flow of materials and a backward flow of information. Even though researchers have studied the various processes of the supply chain individually, there has been an increasing attention placed on the performance, design and analysis of the supply chain as a whole (Beamon, 1998).

Specifically, for the last two decades, there has been an increasing number of studies to optimize the overall supply chain network in order to decrease the overall cost or maximize the total revenue (Tahseen and Amos, 2010). In those studies, the number, location, capacity and type of plants, warehouses and distribution centers and the network traffic among those nodes are to be determined and optimized (Altiparmak et al, 2006). Those are strategic level SC decisions because they have long – lasting effect on the firms' supply chain performance and the decisions cannot be changed in a short term.

Detailed literature review on SC Network Optimization Problems showed that, in most of SC network optimization studies, the structure of the supply chain network is considerably simplified (e.g., a single product and a single location layer are usually assumed), and there is still need for more comprehensive models that simultaneously capture many aspects relevant to real-life problems such as the competition dynamics on the market.

Literature review on SC network optimization problems also showed that almost all of the SC network optimization models ignore the impacts of SC network decisions on the customer demand. However, the physical network structure of a SC is one of the important factors impacting chain's competitiveness, especially for the retail markets. On the other hand, competitive facility location problems model only distribution part of the SC even though they have some characteristics of SC networks and analyze the rival chains existing on the market.

On this dissertation study, in order to include the impact of physical network structure of a SC on customer demand and other SC objectives, a new SC network optimization model on which the concept of SC network optimization modeling is simultaneously utilized with competitive facility location models is proposed. Main distinguishing attribute of the proposed model is its simultaneously modeling of how the closeness of the SC nodes to the customer impacts the competition on the market.

The proposed model is defined as multi objective since SC networks are multi objectives in their nature. The objectives utilized in the proposed model are; profit maximization, sales volume maximization and SC risk minimization. Besides, profit maximization, objective of the sales volume maximization is also utilized within the model since the model company also aims to increase its sales by reconfiguring its SC network and probably by opening new Distribution Center(s) (DC). Third objective function defined in the proposed model is risk minimization. Since SC risks have enormous effect on the long – term and short term SC and financial performance of the companies (Hendricks and Singhal (2005), in every strategic level SC network studies, how SC network configuration decisions influence SC risks needs to be simultaneously modeled.

The proposed model is applied to a real life problem of one of the leading ready – wear clothing companies primarily based in Turkey. In this real life problem, demand is thought to be substantially influenced by the configuration of the SC network, specifically by the location and the number of the DCs.

Since the proposed model will be the first model incorporating the changes in the demand, which is subject to both price and distance from the end-customers and which is substantially influenced by strategic level SC network decisions, the study will also contribute to the Supply Chain Network Optimization model literature. As explained in the following sections, there are some studies, in the current literature, modeling demand as product of competition factors such as price and competitor’s price on the market.

However, none of those models includes any attraction function in their demand model such as distance from the customers, availability of the products etc. which are also subject to SC network modeling decisions. This model will also be the first model simultaneously utilizing supply side risk analysis, demand functions and strategic level SC decisions.

In the next chapter of the dissertation, a brief description of the Supply Chain Management and SC network optimization problems are presented. Along with the definition and concept of the SC network optimization models, an expletory process of the SC network optimization is also provided. Chapter 3 is devoted to detailed review of the SC network optimization literature. In this chapter, first, pioneering SC network optimization studies are presented. After that, non-deterministic models which also aim to model the uncertainty within the SC are introduced. In the last part of the chapter, a detailed analysis of the SC network optimization models developed during the last five years (between 2009 and 2013) is presented. Chapter 4 focuses on "Competitive Facility Location Problem" which defines how the location decisions influence the demand on distribution part of the SC. In Chapter 5, first, problem definition of the real life case and developed model is presented. After the detailed definition of the model, the model results are presented. In the last part of the chapter, a sensitivity analysis on the model parameters is provided. The dissertation ends with conclusions of the study and possible future research suggestions.

CHAPTER 2. SUPPLY CHAIN MANAGEMENT AND SUPPLY CHAIN NETWORK MODELING

Before getting into the details of the SC network modeling literature, a brief description of the SC Management and SC decisions are presented in this chapter. Along with the definition and concept of the SC network optimization models, an expletory process of the SC network optimization is also provided.

2.1. Supply Chain Management

During 80's, companies applied new manufacturing technologies and strategies such as just-in-time manufacturing, Kanban, lean manufacturing, total quality management to reduce costs and better compete in different markets. After applying these technologies and the strategies, companies have reduced manufacturing costs as much as possible and now focused on effective SC management to reduce the total cost across the overall supply chain (Simchi – Levi, 2003).

There are various definitions of the Supply Chain. Beamon (1998) defines supply chain as an integrated effort where various entities (suppliers, manufacturers, distributors, and retailers) work together in order to: acquire raw materials, convert these materials into specified final products, and deliver these final products to the retailers. This chain is traditionally characterized by a forward flow of materials and a backward flow of information.

In another definition, Supply Chain Management is defined by Simchi – Levi (2003) as a set of approaches utilized to integrate entities within the supply chain (suppliers, manufacturers, warehouses, and stores), so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time. According to Simchi – Levi (2003), the main objective of the supply chain management is to minimize system-wide costs while satisfying service level requirements. Therefore, even though researchers have studied the various processes of the supply chain individually, there has been an increasing attention placed on the performance, design and analysis of the supply chain as a whole (Beamon, 1998).

The supply chain consists of suppliers, manufacturing centers, warehouses, distribution centers, and retail outlets, as well as raw materials, work-in-process inventory, and finished products that flow between the facilities. Increasing competition, shorter product life cycles, and the heightened expectations of the customers have forced enterprises to focus more attention on the whole supply chain, instead of the individual entities of the chain. In a typical supply chain, raw materials are procured and items are produced at factories, shipped to warehouses for intermediate storage, and then shipped to retailers or customers. Therefore, to reduce cost and improve service levels (main SC objectives), effective supply chain strategies must take into account the interactions at the various levels in the supply chain (Simchi – Levi, 2003).

2.2. Decision Phases in a Supply Chain Management

After a brief description of the SC and SC management, critical decisions and decision categories on SC management is defined on that section in order to show readers why SC network modeling is a critical part of strategic level SC planning.

The main objective of every supply chain is to maximize the value generated through product and information flows. The firms need to make decision on several critical issues to effectively manage their supply chains. However, before introducing these SC decisions, those decisions need to be categorized.

According to Sunil and Chopra (2003), the supply chain decisions are categorized based on the frequency with which they are made.

1. **SC Strategy and Design:** During this phase, the firm configures its SC over the next several years. Firm must ensure that the SC configuration supports its strategic objectives and increases the supply chain surplus. Decision in that phase includes

what the chain's configuration will be, how resources will be allocated, whether to outsource or perform a supply chain function, the location and the capacities of SC nodes, the products to be manufactured or stored at various locations, mode of the transportation to be used, and the type of the information system utilized.

2. **Supply Chain Planning:** Decisions made in that phase is generally assumed to be made for a term of a quarter to a year. Supply chain configuration is assumed to be given. The planning phase generally starts with a demand forecast for the coming year. Planning decisions include which markets to be supplied, the subcontracting of manufacturing, the inventory policies to be followed, and the timing and size of the marketing and price promotions. That category is sometimes called tactical level.

3. **Supply Chain Operations:** This phase includes decisions regarding individual customer orders. The time horizon is weekly or daily. At that level, supply chain configuration is assumed to be fixed and the planning policies are defined. During this phase, firm allocates inventory or production to individual orders, set an order fill date, pick lists at a warehouse, allocate orders to the shipment mode and shipments, set delivery schedules, and place replenishment orders.

Simchi and Levi (2003) also categorizes the SC decisions in a very similar manner and also points out key SC decisions, questions and trade-offs as follows.

1. ***Distribution network configuration;*** a set of warehouse locations and capacities, production levels for each product at each plant, and transportation flows between facilities, either from plant to warehouse or from warehouse to retailer, in a way to minimize total production, inventory, and transportation costs and satisfy service level requirements have to be decided under this heading.

2. ***Inventory control;*** the objective is to decide at what point to reorder a new batch of the product, and how much to order so as to minimize inventory ordering and

holding costs. It also considers the underlying reasons behind the uncertainties and tries to minimize these uncertainties such as in customer demand, supply process or some other reasons. Also the optimal inventory turnover ratio to be utilized need to be determined.

3. ***Production sourcing;*** the firms also need to decide about the set of product mix among different plants. In case, each manufacturing facility is responsible for a small set of products so that large batches are produced, hence that reduces the production costs. Unfortunately, this may lead to higher transportation costs. Therefore, the firms need to plan carefully at which facility which products need to be manufactured in order to find the right balance between transportation costs and manufacturing costs.

4. ***Supply contracts;*** supply contracts define the relationships between suppliers and buyers. These contracts specify pricing and volume discounts, delivery lead times, quality, returns, and so forth.

5. ***Distribution strategies;*** the firms also need to decide how much they should centralize (or decentralize) their distribution system. The impact of each strategy on inventory levels, transportation costs, and service levels need to be analyzed. The firms also need to decide by which transportation mode they should utilize to transport products.

6. ***Supply chain integration and strategic partnering;*** an integrated, globally optimal supply chain can have a huge impact on the company's performance and market share. In today's competitive markets, companies are forced to integrate their supply chain and engage in strategic partnering. Therefore, the firms need to decide on the level and the type of the strategic partnership and also consider on how to achieve integration with the strategic partners.

7. ***Outsourcing and offshoring strategies;*** rethinking the supply chain strategy also includes deciding what to make internally and what to buy from outside sources. In order firms to utilize effective outsourcing and offshoring strategies, the firms need to answer below questions;

   - How can a firm identify what activities lie in its set of core competencies, and thus should be completed internally, and
   - What product, components and services should be purchased from outside suppliers, because these activities are not core competencies?
   - What are the risks associated with outsourcing and how can these risks be minimized?
   - When do you outsource, how can you ensure a timely supply of products?
   - Finally, even if the firm decides not to outsource activities, when does it make sense to move facilities to the Far East?
   - What is the impact of offshoring on inventory levels and the cost of capital?
   - What are the risks associated with offshoring?

8. ***Product design;*** since certain product designs may increase inventory holding or transportation costs relative to other designs, while other designs may facilitate a shorter manufacturing lead time it may be concluded that effective product design plays several critical roles in the supply chain.

9. ***Information technology and decision-support systems;*** Information technology plays a critical role in effective supply chain management. Indeed, much of the current interest in supply chain management is motivated by the opportunities that appeared due to the abundance of data and the savings that can be achieved by sophisticated analysis of these data.

10. ***Smart pricing;*** in recent years, a number of firms' carriers have applied a variation of smart pricing techniques to improve supply chain performance. The firm integrates pricing and inventory (or available capacity) to influence market demand.

2.3. Supply Chain Network Optimization Models

As explained in the previous section, SC network optimization and configuration is one of the critical and strategic level SC decisions. In this section, the definition of and brief information about these SC network optimization models is provided and the data requirements for those models are presented. The section ends with an explanation of the processes of building and running SC network optimization models.

2.3.1. Supply Chain Networks

Simchi and Levi (2003) defines supply chain networks as being consisted of suppliers, warehouses, distribution centers, and retail outlets as well as raw materials, work-in-process inventory, and finished products that flow between the facilities.

Supply chain networks are generally represented as in Figure 1. In the figure, the nodes represent the facilities while the arrows represent the direct transportation networks permitted by the organization managing the supply chain. Network models are useful to depict and discuss the model; however, it provides only a high level view of the supply chain (Shapiro, 2001).

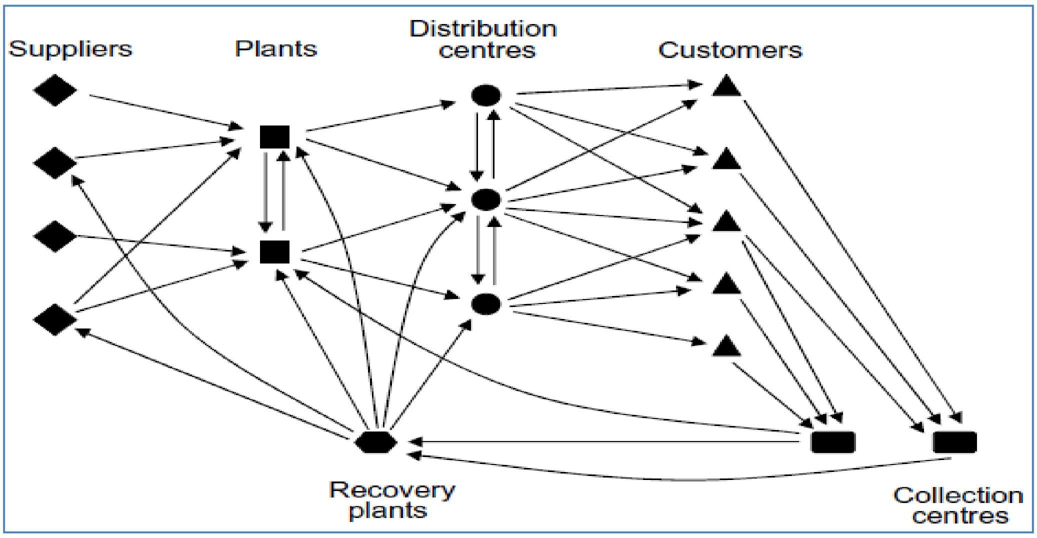

Figure2-1. Supply Chain Network (Melo et. al., 2009)

2.3.2. Supply Chain Network Optimization Models

Supply Chain network optimization models may be defined as models designed to minimize costs or maximize profit by providing the customer the right goods, in the right quantity, at the right place, and at right time.

Wagner et al (2008) defines network optimization models as a class of mathematical programming models formulated to represent all the high level activities within the SC. In the model, raw materials, work-in-process and finished products flow through the network.

Models are built and utilized to answer below questions (Chopra and Meindl, 2006 & Simchi and Levi, 2003, and Shapiro, 2001);

- Appropriate number and location of warehouses
- What should be the configuration and strategy of each production plant and DC?
- Which suppliers should be used to supply which plants?
- Which group of customers should each DC service?
- How will customers order from and how will each DC be replenished?
- How should shipments be scheduled?
- What should the service levels be?
- Which supply chain transportation methods should be used?

These decisions are strategic decisions because they have long – lasting effect on the firms' supply chain performance and the decisions cannot be changed in short term.

Traditionally, main focus of the SC network optimization models has been regarding minimizing the overall cost or maximizing the total revenue (Tahseen and Amos, 2010). That is, while designing their supply chain networks, firms must evaluate their impact on customer service and cost factors as it compares different network configuration options.

2.3.2.1. *Customer service factors influencing the SC network configuration*

Different network configuration decisions influence below customer service factors of supply chain (Chopra and Meindl, 2006).

- *Response Time;* amount of time it takes for a customer to receive an order
- *Product Variety;* number of different products that are offered by the network
- *Product Availability;* probability of having a product in stock when a customer order arrives.
- *Customer Experience;* the ease with which customers can place and receive orders
- *Time to Market;* the time it takes to bring a new product to the market.
- *Order Visibility;* the ability of customers to track their orders from placement to the delivery
- *Returnability;* the ease with which customers can return an unsatisfactory merchandise

At the first glance, it may seem that a customer always want the highest level of performance at all the dimensions of the customer service level factors. In practice, this is not true. For example, people who shop over the internet may be willing to wait longer, however, may be enjoying having more choices compared to shopping from stores. Thus, the choices of the targeted customers have enormous influence on the firms' network decisions. Firms targeting customer who can tolerate longer response time may have only a few locations far from customers. In contrast, firms targeting customers who value shorter response times need to locate facilities close to customers. Thus, a decrease in the response time increases the required number of facilities (Chopra and Meindl, 2006).

2.3.2.2. Cost factors influencing the SC network configuration

Changing the distribution network design substantially affects the following supply chain costs:

- Inventories
- Transportation
- Facilities and handling
- Information

Inventory costs; when firms consolidate and limit the number of facilities in their supply chain network that would decrease inventory costs due to consolidation effect.

Transportation Costs; Inbound transportation costs are the costs incurred in bringing material into a facility. Outbound transportation costs are the costs of sending material out of a facility. Increasing the number of warehouse locations decreases the outbound distances and the outbound transportation costs. Thus, as long as inbound transportation economies of scale are maintained, increasing the number of facilities decreases total transportation costs.

Facility costs decrease as the number of facilities is reduced. As the number of facilities increases, total logistic costs first decrease and then increase. Firms should have at least the number of facilities that minimize total logistics costs (Chopra and Meindl, 2006).

2.3.2.3. Data requirements

A typical SC network optimization model requires large amount of data, including but not limited to (Chopra and Meindl, 2006 & Simchi and Levi, 2003,Wagner et al. 2008, and Shapiro, 2001);

- Existing and potential locations of SC nodes; Location of existing and potential customers, retailers, existing warehouses and distribution centers, manufacturing facilities, and suppliers.
- Definition of products;
    - All products, including volumes, and special transport modes (e.g. refrigerated)
    - Bill of material for each product.
    - Definition of manufacturing at each plant (special requirements, costs etc.)
- Demand data;
    - Annual demand forecasts for each product by customer location
    - Sale price of a product in different regions.
    - Customer service requirements and goals.
- Cost and capacity data: Network optimization models require definition of real world cost and capacity elements which includes;
    - Transportation rates by mode and by volume.
    - Warehousing costs, including labor and inventory carrying costs as a function of quantity
    - Fixed operating costs for each potential facility.
    - Capacities for plants, warehouses and customer locations.
    - Capacities for transportation modes.
- Shipments sizes and frequencies for customer delivery.
- Taxes and tariffs, if applicable.

2.3.3. SC Network Optimization Process

After briefly introducing SC network optimization models, a process for designing SC network optimization models also needs to be provided. Wagner et al. (2008) proposes a four stage process to build those models;

2.3.3.1. Identify SC scenarios

Even though some of the models are built to evaluate the current scenarios, sometimes, firms may need to build the models to evaluate them under some scenarios. In this stage, firms need to identify a wide range of alternative scenarios to manage the SC. The scenarios need to be aligned with the firms' business strategy and the qualitative assessments of the proposed alternatives need to be provided on that stage of the process.

2.3.3.2. Design and build network optimization model

Model structure is created on that stage. Generally vendor, product and market aggregations are established to simplify the model. For a recent period, o model is created using historical shipping and production data aggregated into model groups. The current cost and capacity is defined for all entities and for transport arcs between entities. Processing activity and product flows between entities are modeled according to historical data. This fully constrained model is called validation model. In the validation model, all current facilities are forced to be active. This validation model is used to establish a baseline for alternative scenarios and to verify the accuracy of the model data.

2.3.3.3. Optimize model scenarios

In this stage, the model is run for each scenario developed on stage 1 to quantify the expected returns. General strategy is as follows:

- Model each of the approaches to understand relative differences among approaches.

- For superior 3 to 5 approaches, execute the models that reflect various level of demand and cost to understand the sensitivities of the models.
- For likely investments and closure decisions, run models to display the marginal costs / benefits

Stage 3 is iterative and directed by the output of previous model runs. After each series of run, a dynamic selection and fine-tuning of the models is required.

2.3.3.4. Determine future SC vision

On this stage, the information regarding the alternative SC configurations is assessed and the sensitivity of these configurations to various changes to demand, cost and other key data, and marginal costs are analyzed.

Once the best alternative configuration is defined and confirmed, detailed implementation plan must be developed. Changes to the network may include building new manufacturing or distribution facilities, closing existing ones, changing the mode of transportation etc.

CHAPTER 3. SC NETWORK MODELING LITERATURE REVIEW

SC network optimization and modeling is a well-established research area within SC context and the number of studies on this issue has grown substantially over the last decade. Supply Chain Network Design and optimization problems cover wide range of studies ranging from one product to multi product models, from two tier networks to more complex networks, from deterministic models to stochastic models, and mathematical models to heuristic solution models.

In previous chapter, a theoretical and conceptual framework on SC networks and SC Network optimization models is provided to give a brief understanding about these models and why they are used. In this chapter, SC network modeling studies are reviewed and the results of the literature review are given.

The remainder of the chapter is organized as follows: First, pioneering SC network optimization studies are presented to provide a brief background of SC network optimization models. After that, non-deterministic models which also aim to model the uncertainty within the SC are introduced. Then, a detailed analysis of the SC network optimization models developed during the last five years (between 2009 and 2013) is presented. In the last section of the literature review, a detailed literature review specifically focused on multi-objective SC network models is presented in order to guide readers on the multi-objective methods which may be utilized on the proposed model. The chapter ends with final conclusions about the current literature and a model proposal which aims to close one of the gaps at the current literature.

3.1. Pioneering Studies

As mentioned above, in this section pioneering SC network optimization studies are presented to provide a brief history of how SC network optimization models developed. The section starts with several earliest studies (Cohen&Lee, 1987; Cohen & Lee, 1989;

Cohen & Moon, 1990). Then, some major studies (Arntzen et. al, 1990; Camm et. al, 1997) helped those models to accepted widely are presented. The section ends with several other earlier studies (Sabri & Beamon, 2000; Talluri & Baker, 2002) which integrated SC network models with other models such as supplier selection models, route optimization models etc.

3.1.1. Cohen & Lee, 1987 – PILOT Model

In late 80's (1987), Cohen and Lee presented a model framework for linking decisions and performance objectives throughout the material – production – distribution supply chain. Their model called PILOT (Production Inbound and Outbound Transportation model) attempted to formulate, link and optimize the complex system of four sub-models required to analyze integrated supply chain. Sub-models are;

- Material Order Sub-model
- Production Lot-size Sub-model
- Finished Good Stockpile Sub-model
- Distribution (inventory) Sub-model

Within the model, the authors suggest a normative framework which involves use of periodic (annual), deterministic optimization models to specify structural decisions. The detailed cost and service consequences of the decision variables are predicted with the aid of aggregate, dynamic planning models. The overall performance measure of the model is total cost required to achieve a predetermined service targets (Cohen and Lee, 1987).

3.1.2. Cohen&Lee,1989 – Global Manufacturing and Distribution Network Model

In 1989, Cohen and Lee developed their model and presented Global manufacturing and distribution network model. Global manufacturing model incorporated the product design, manufacturing and distribution networks.

The objective of the presented model was to maximize the after tax profit through the design of the facility network and control of material flows within the network. The authors applied model to the analysis of global manufacturing strategies for a personal computer manufacturer.

The authors build a mathematical model to analyze the resource deployment decisions. In the model, one – year period for the analysis is applied and the products are aggregated to one simple product. The constraints of the model included facility capacity, regional demand requirements, material balance, and government offset requirements. The cost structure contained variable and fixed costs for material procurement, production, distribution, and transportation. The model also accounted for tariffs, duties, and transfer pricing.

Even though the authors build a comprehensive model and also covered global issues such as tariffs and duties, the model was deterministic and did not capture risk factors that exist in the global chains, such as currency exchange rates risks, demand level risks, prices etc.

After applying model to the PC manufacturer company, the authors concluded that the profit rates, under various alternatives did not vary significantly. However, the resource deployment decisions varied considerably under each alternative since the model finds the best material flows and plant product mixes for the logistics structure defined by the alternative strategy (Cohen & Lee, 1989.

3.1.3. Cohen & Moon, 1990

In 1990, Cohen and Moon used PILOT model to analyze the relationship between manufacturing and distribution cost structure and characteristics of supply chain strategy. The developed model accepts various production and transportation costs as inputs, and consequently outputs;

- ✓ Which of the available manufacturing facilities and distribution centers should be open.
- ✓ Raw material and intermediate order quantities for each vendors and manufacturing facilities.
- ✓ Production quantities of product by each manufacturing facility.
- ✓ Product-specific shipping quantities from manufacturing facility to DCs and from DCs to customer points.

The objective function of the PILOT model is a cost function, consisting of fixed and variable production and transportation costs, subject to supply, capacity, assignment, demand, and raw material requirement constraints (Cohen and Moon, 1990).

3.1.4. Arntzen et al., 1990 – Global Supply Chain Model (GSCM)

In 1990's, Arntzen et al. build a supply chain model based, called Global Supply Chain Model (GSCM) on mixed integer programming (MIP). GSCM incorporates a global, multiproduct bill of materials for supply chains with arbitrary echelon structure. Intent of the study was to build supply chain network which minimizes the total cost, including, production cost, distribution costs, and inventory costs etc. by looking not only at location selection of facilities but also the production, inventory and shipping quantities. GSCM is applied to Digital Equipment Corporation, third largest vertically integrated computer company in the world, to evaluate supply chain alternatives and determine worldwide manufacturing and distribution strategy.

GSCM had two objectives. Besides cost minimization; the model also aims to minimize the total amount of days required for production and transportation between each connection in the supply chain. Both cost and time variable objectives are subject to meeting estimated demand and restrictions on local content, offset trade, and joint capacity for multiple products, echelons and time periods. Objectives are weighted in the single objective function.

The major contribution of that study was the consideration of the trade balance, local content, and duty constraints in an international SC network configuration model (Arntzen et al, 1990).

3.1.5. Camm et. al., 1997

Another empirical application of supply chain network model is developed by Camm et al. in 1997. In the study, the authors reexamine the North American supply chain of Procter & Gamble Company with an emphasis on plant consolidation. In the proposed model, the overall supply chain problem is decomposed into two sub-problems: a distribution location problem and a product sourcing problem.

- Distribution Center Location model: An uncapacitated an integer programming facility location model to find optimal DC locations and to assign customers to DCs. The objective of the model is to minimize the cost of all DC – customer zone assignments.

- Product – sourcing model: A simple transportation model for each product category. In the model, each DC is treated as a customer demand location with a total demand assigned by DC location model. The objective of the model is the minimization of the total costs which are the sum of manufacturing, warehousing at the plant, and transportation costs. The product sourcing model is also integrated with the Geographical Information Systems (GIS) to provide a powerful and flexible decision support system (Camm et. al, 1997).

3.1.6. Integrative Approaches - Sabri & Beamon, 2000

Even though many different factors must be taken into account when designing a new SC, most of the developed Supply Chain Network models study only isolated parts of the SC for the sake of simplicity. Through the development of the SC Network modeling concept, some papers integrating decisions regarding procurement, routing and the choice of transportation modes with other decisions, in particular those focusing on the strategic planning level emerged. In this section of the literature review, two samples of integrative approaches are presented.

In 2000, Sabri and Beamon presented a SC network optimization model for simultaneous strategic and operations planning of the SC. They adopted multi-objective decision analysis to allow use of several performance measures simultaneously that includes cost, customer service levels (fill rates), and SC flexibility. The model is divided into two sub-models; the strategic sub-model and the operational sub-model.

- The strategic sub-model's objective is to optimize the supply chain configuration and material flow.

- The operational sub-model is integrated with the strategic model in order to incorporate the uncertainty of production, transportation and distribution.

When the output variables of the strategic sub-model have been determined, customer demand, required service and flexibility levels, cost, lead times etc. are estimated under uncertainty. The model is based on an iterative structure, first one optimizes the strategic sub-model for an existing or a proposed supply chain configuration, after that the output variables from the strategic sub-model are sent to the operational sub-model as input data and the operational sub-model is optimized based on the determined supply chain configuration. Output variables from the operational optimization runs are sent back to the strategic sub-model where a new optimization is performed with the new variables which also incorporate uncertainty.

In order to solve multi-objective problem within the model, authors use ε-constraint method which transforms multi-objective problem into a single objective optimization problem (Sabri and Beamon, 2000).

3.1.7. Integrative Approaches - Talluri & Baker, 2002

In another multi-stage study, Talluri and Baker propose a mathematical programming approach for SC network design, which involves a variety of techniques such as multi-objective efficiency models, based on game theory formulations, and linear and integer programming methods. They decompose SC network modeling problem into 3 phases;

- Phase I concentrates on potential suppliers, manufacturers, and distributors, and evaluates their efficiencies based on multiple factors. In that phase (Supplier Selection Phase), numerous factors are blended into a single performance index.

- Phase II designs the SC network at an aggregate level by matching supply and demand of all potential nodes, and at the same time optimizes the SC network meeting the network efficiency and location standards set by the decision maker (Strategic Level SC Optimization).

- Phase III analysis addresses operational issues that include optimal sourcing and deployment plans for all network nodes through a minimum-cost transshipment problem (Operational Level SC Optimization). That phase needs to be run more frequent than the other two phases due to changes in demand and capacity constraints in the short run (Talluri and Baker, 2002).

3.2. Non-Deterministic SC Network Models;

All of the models presented in the previous section are deterministic analytical models, in which the variables are known and specified. However, in reality, SC operates in an uncertain environment. Uncertainty is associated with customer demand, and internal and external supply deliveries throughout the chain. In this section of the literature review, several examples of non-deterministic models are introduced. All models introduced either in previous section or in this section, along with some other models, are also summarized with various features of the models on a table as Appendix I.

Supply Chain network models are divided into four categories by the modeling approach (Beamon, 1998). (1) Deterministic models in which all variables are known and specified. The other three types of models aim to model the uncertainties. (2) Stochastic analytical models, where at least one of the variables is unknown, and is assumed to follow a probability distribution. (3) Simulation models where simulation techniques are used to cope with the uncertainties within the model and (4) Fuzzy Based (Probabilistic) models where fuzzy set theory based models are used to handle the uncertainty within the SC.

3.2.1. Stochastic Models

In 1988, Cohen and Lee developed a hierarchical, stochastic network model for establishing a material requirements policy for all materials for every stage in the supply chain production system. In this work, the authors use four different sub-models. There is one stochastic sub-model for each production stage considered. These sub-models and how the uncertainty within these sub-models is modeled briefly introduced;

1. Material control: Establishes material ordering quantities, reorder intervals, and estimated response times for all supply chain facilities. In order to handle with the uncertainty, the material control sub-model models the randomness of both demand process for materials and the supply lead times.

2. Production control: Determines production lot sizes and lead times for each product. The authors included queuing relationship for each work center.

3. Finished goods stockpile (warehouse): Determines the economic order size and quantity for each product. Within the sub-model, the lead time for delivery of stock to the distribution system depends on the transportation time from plants to the distribution centers, availability of inventory, and the production lead time.

4. Distribution: Establishes inventory ordering policies for each distribution facility. That sub-model generates the demand for finished products. There is random lead time distribution offered to the central distribution node (Cohen and Lee, 1988).

Guillen et. al. (2005) build a stochastic – two stage, multi objective model to design a supply chain consisting of several production plants, warehouses and markets, and the associated distribution system. The model developed by the authors includes a three echelon SC (production – storage – customer market) and aims to maximize two objectives; the net present value, the demand satisfaction and minimize financial risk, which is defined as the probability of not meeting a certain profit aspiration level (three objectives).

The model includes decisions on the capacity and the location of the plants and warehouses, the amount of products to be made at each plant, and the flows of materials between the nodes of SC.

The authors propose two stage stochastic optimization approach to incorporate the uncertainty associated to the demand within the design process. The uncertain model parameters (demand variables) are considered random variables with an associated probability distribution.

- At the first stage of the model, the binary decision variables which characterize the network configuration, and continuous variables which are related to the capacities of the sites are determined.

- After the first stage of the model, the uncertainty is unveiled. Uncertainty associated with the demand is represented by a set of scenarios (100 random scenarios) with given probability of the occurrence. Such scenarios are provided as input data into the model.
- At the second stage of the optimization, decision variables related to the amount of products to be produced and stored at the potential sites, the amount of materials transported among SC nodes and sales volume is determined.

At the end of the each scenario runs, a different value of NPV and demand satisfaction is obtained for each particular realization of demand uncertainty. The model accounts for the maximization of the expected value of the profit distribution (weighted average of the profits), the target imposed for the customer satisfaction and the financial risk.

Multi objectivity is handled by applying the ε-constraint method. In the proposed model, one objective (NPV) is maximized while considering the other objectives as constraints bounded by some allowable level. Then allowable level is altered to generate a pareto optimal solution set.

3.2.2. Simulation Based Models

Simulation may be defined as the process of designing a model of a real system and conducting experiments with the designed model for the purpose of both understanding the system behavior or evaluating the various scenarios (Shannon, 1975). The simulation methods are used for analysis of complex real systems such as supply chain networks. Simulation methods help supply chain network modelers to model the unanticipated changes in uncertain variables such as demand, order or production quantities and lead times.

While analytical SC network models are more related to strategic level SC decisions such as location/allocation decisions, demand planning, distribution channel planning, strategic alliances, outsourcing, supplier selection, pricing, etc., simulation models tries to build a more realistic capture of the supply chain characteristics and provide a tool to analyze the impact of the tactical level of policy changes in supply chain such as inventory control, production distribution coordination, order/freight consolidation, material handling, equipment selection and layout design (Hung et. al., 2004 and Ozbayrak et. al., 2007).

During 90's and 2000's, many simulation based SC network optimization models have been studied. Most of these studies differ in the simulation techniques utilized within the model and how the uncertainty within the SC is modeled. In a simulation model, Wikner et. al. (1991) use simulation techniques to evaluate the effects of various supply chain strategies on demand amplification. The authors used a three-echelon production distribution system to investigate the effects of:

- Modifying the parameters of the existing order quantity procedures.
- Implementing a just-in-time (JIT) inventory policy to reduce time delays.
- Eliminating the distribution echelon of the supply chain, by including the distribution function in the manufacturing echelon.
- Improving the movement of intermediate products and materials by modifying the order quantity procedures.
- Integrating the flow of information throughout the supply chain.

The implementation of different strategies is carried out using simulation techniques. The objective of the research was to determine which strategies are the most effective in smoothing the variations in the demand. The authors concluded that the most effective strategy in smoothing the demand is improving the flow of the information at all levels of the supply chain (Wikner et al., 1991).

In 2006, Ding et. al. developed "ONE" (Optimization methodologies for Networked Enterprises) Model, the coupling of simulation and optimization, and the explicit management of uncertainty. The ONE model included following modules:

- *The network module* supports the development of the network modules under the consideration of uncertainty and variability.
- *The optimization module* offers a set of optimization methods including mathematical programming (MP) and genetic algorithm (GA)
- *The statistical data miner* offers a set of data mining methods in order to improve the SC network evaluation with company specific data.
- *The simulation module* for the evaluation of enterprise network models.

Within the ONE model, the following steps are recommended to analyze the SC network;

- First step; the identification of the problem and scenario (number and location of the possible plants, suppliers, DCs etc.)
- Second step; the modeling of the scenario using network model. All the required input data, such as production line characteristics, demand, costs, time and uncertainties, is entered to the system.
- Third step; the identification of the key performance indicators (KPI) that is demanded for the assessment of the different alternatives.
- Fourth step; Different configurations are simulated and evaluated.

The authors developed and integrated a simulation based multi-objective optimization method for joint optimization of SC network and operational parameters (inventory parameters, transportation parameters etc.). More specifically, multi-objective genetic algorithm is adapted to perform stochastic search for solutions, which achieves a trade-off regarding conflicting criteria, e.g. costs and customer service level. Decisions are incorporated into discrete – event simulation models for the evaluation of KPIs.

In a recent study, Stefanovic et. al. (2009) proposes a generic approach for supply chain modeling. In order to model the supply chain network, authors use a process based approach (SCOR). SCOR (Supply Chain Operations Reference) is defined as a universal approach to supply chain management. According to SCOR, SC management consists of the following integrated processes:

- Plan – asses supply resources, demand requirements, plan inventory, production, and material requirements
- Source – Purchase, reception, stocking, issuing, and payment authorization
- Make – Request and receive materials, manufacture and test products, quality control, stocking, and/or release products
- Deliver – Execute order management and fulfillment processes, shipment, and measure performance.
- Return – Reverse logistics

SCOR model contains three levels of process detail. The top level defines the scope and content of the supply network and sets the performance targets. At the second level, the intersection of process and process types forms process categories. The third level includes the process elements and their process flows. That level of the model is very significant for the simulation and simulation studies are run using the data defined at that level. Each process element defined at third level has the following attributes: process ID, process name, standard definition, performance metrics, best practices (where applicable), and finally, inputs and outputs.

One of the most important and influential factors in the proposed model is customer demand, since it governs and directs the entire supply network. The model takes customer demand into account and allows defining different order types that have a major influence on the entire model. Demands can differ by the order processing method, order validity period, priorities, etc.

After the modeling is done and the initial parameters are set, customer demand is generated. After that, the simulation is run; it triggers one or more other processes. Each process is expressed in terms of time, costs and resources. Within the proposed model, all characteristics of SC network such as machine line capacity, transportation resource capacity and speed, worker performance, etc. are to be modeled.

3.2.3. Fuzzy Based (Probabilistic) Models;

Besides stochastic models and simulation based models, fuzzy logic theory based models are also used in order to cope with the uncertainties within the strategic level SC models. The term "fuzzy logic" was introduced by Lotfi A. Zadeh in 1965 to handle uncertainties. Fuzzy logic is a form of probabilistic logic; it deals with reasoning that is approximate rather than fixed and exact. Unlike to traditional binary sets, fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic may also be used to handle the concept of partial truth, where the truth value may range between completely true and completely false.

According to Kabak and Ulengin (2011), 4.1 % of the SC network modeling studies uses fuzzy set theory models in their researches. Most of these studies utilize fuzzy theory based models to handle the uncertainties in demand, and price. Two examples of these models are presented in this section.

Chen and Lee (2004), in their paper, propose a multi-product, multi-stage, and multi-period scheduling model to deal with multiple objective for a multi-echelon supply chain network. The authors incorporated two kinds of uncertainties; the market demand and product prices. The authors modeled the uncertain market demands as a number of discrete scenarios with known probabilities. The fuzzy sets are used to describe the sellers' and buyers' incompatible preference on product prices.

The supply chain scheduling model is constructed as a mixed-integer nonlinear programming (MINLP) problem. The problem is formulated to achieve fair profit distribution among all participants, safe inventory levels, maximum customer service levels, maximum robustness to demand uncertainties, and to guarantee maximum acceptability levels of sellers' and buyers' preference on prices. To find the degree of satisfaction of the multiple objectives, Chen and Lee used the linear increasing membership function; the final decision is acquired by fuzzy aggregation of the fuzzy goals and the fuzzy product prices, and the best compromised solution is derived by maximizing the overall degree of satisfaction for the decision.

Kabak and Ulengin, in their profit maximization model, propose a fuzzy set theory-based model to deal with uncertainties. The model considers demand and yield rates as uncertain variables and treats them as fuzzy variables. The authors use a possibilistic linear programming (PLP) model to make strategic resource planning decisions. In the model, the coefficients of the decision variables are fuzzy numbers, while the decision variables are crisp. On the other hand, in the PLP formulation, the decision variables are obtained as fuzzy numbers, while the coefficients of the decision variables may be either crisp or fuzzy.

In this study, the PLP model is first converted to an LP model by using mathematical operations defined for triangular fuzzy numbers (TFNs) because it is easy to apply mathematical operations to TFNs. Then, objective functions are normalized in order to compute the values of fuzzy objective functions. For this purpose, a linear programming model (LP-1) is proposed to find the lower and upper bounds of the profit function. In LP-1, all the decision variables and constraints are defined by crisp numbers. The objective function of LP-1 is the defuzzified version of the first objective function in the PLP. Once the normalization formulas for the objective functions are defined, the PLP model is converted to linear form (LP-2). The basic aim of LP-2 is to maximize the lower bound of the normalized objective functions of the PLP.

In their research, the authors apply the proposed model to Mercedes–Benz Turk, one of the largest bus-manufacturing companies in the world in order to optimize the resource utilization of the company (Kabak and Ulengin, 2011).

3.3. Literature Review for Latest Studies

At the beginning of the literature review, pioneering SC network optimization studies, in a chronological order, are provided to give an idea about how these models evolved. Then, non-deterministic models which aim to model the uncertainty within the SCs are also introduced. In this section of the literature review, a detailed analysis of the SC network optimization models developed during the last five years is presented, along with a final conclusion about the current literature.

3.3.1. Review Methodology

In this review, the main focus was on the articles which include "strategic level supply chain network model". Besides that, research fields which have close relationship with SC network models have been briefly reviewed to understand which research fields recently benefit from or contribute to SC network models.

In order to generate a list of related articles within year 2009 and 2013, "supply chain network modeling" keywords are used to make a search under "Science Direct" library database. Then, in order to narrow down the articles, major journals within the scope of operations research, supply chain, decision support systems etc. are selected. As a result of this selection procedure, a list of 495 articles is generated. Below on Table 3.2, is a list of journals in the list. The number of articles for each journal is also provided on the Table.

Table 3-1. List of journals with SC network models

Journal	# of Articles
International Journal of Production Economics	169
European Journal of Operational Research	70
Expert Systems with Applications	61
Decision Support Systems	48
Computers & Chemical Engineering	29
Computers & Industrial Engineering	27
Journal of Operations Management	23
Transportation Research – Part E	22
Computers in Industry	20
Computers & Operations Research	13
Industrial Marketing Management	11
Technological Forecasting and Social Change	2
Total	**495**

3.3.2. Articles without SC Network Models

Since it is not possible to review all 495 articles associated with "Supply Chain Network Modeling", only articles with "Strategic Level SC Network Models (SCNM)" are considered in the detailed analysis. After a review of the articles, it is found that only 71 of these articles include strategic level of SCNMs even though most of the articles have close relationship with SC network modeling area. Table 3-2 depicts the categorization of those articles;

Table 3-2. The categorization of the article survey results

Type	Number of Articles
Strategic Level SCNM	71
Tactical Level SCNM	65
Does not include SCNM	210
Literature Review	19
Survey	6
Irrelevant	124
Total	495

As mentioned earlier, in order to understand which research fields recently benefit from or contributes to SC network models, articles without SCNM have been briefly reviewed. Table 3-3 presents the subject areas of those articles and the number of incidents for each subject area;

Table 3-3. Subject areas of the articles without strategic level SC network models

Subject of the Article	# of the articles
SC Integration, SC Coordination, SC Contracts etc.	73
Inventory Management, Inventory Models and optimization	29
SC Risks, SC Risk Modeling and SC Disruptions	27
SC Performance Metrics, Indicators and Models	16
Green SC	15
Transportation Modeling and Management, Distribution Scheduling	13
Outsourcing and Supplier Selection	12
Bullwhip Effect	10
Dynamic Supply Chain, Agile SC,SC Flexibility	10
Demand Forecast and Demand Management	9
Product Strategies, modularity and product portfolio	7
Production planning and product lot-size optimization	6
SC Processes and operations and SCOR Model	6
Quality Control and Tracing	4
Reverse Logistics	3
Facility Location – Hub Location Problems	3
Others	27

As seen on the table, more than % 27 of the articles covers the subjects such as "SC integration and coordination, how the coordination can be improved and how IT may be used to improve the coordination among SC members and eventually SC performance". So, this can be drawn that there is a substantial interest on SC coordination and how it influences SC network optimization models.

As researchers may already guess, subject areas such as "inventory models and inventory management", and "SC performance model and metrics, performance evaluation models" have also very close relationship with SC network models. Around 17 % of the reviewed articles are on those two subjects.

There are three subjects on which there are increasingly important numbers of articles. Those subject areas are "SC Risks, SC Risk Modeling and SC Disruptions (27 articles - %10)", "Green SC (15 Articles - % 5.6)", and "Dynamic SC, Agile SC (10 Articles - % 3.7)".

Another interesting result which may be drawn from the analysis is that some of the concepts which is thought to have very close relationship with SC network models such as "Transportation and Distribution Modeling and Planning (13 Articles)", "Demand Forecasting (9 Articles)", "Production Planning and Scheduling (6 Articles)", and "Facility Location Problem (3 Articles)" are not coincided as much as expected.

3.3.3. Articles with Tactical Level SC Network Optimization Models

Besides articles that are in the field of SC network models, however, do not include any SC network model, there are also 65 articles that includes tactical level SC network optimization models. On those articles, without reconfiguration of SC network, SC networks are utilized to support tactical level models such as inventory optimization model, distribution scheduling model, production planning and scheduling model etc. Table 3-4 depicts the different types of tactical level SC network optimization models and the number of incident for each type;

Table 3-4. Tactical Level SC Network Models

Type of the Model	Number of Articles
Inventory Optimization Models	22
Distribution Planning and Scheduling, Vehicle Scheduling	19
Production and Assembly Planning and Scheduling	17
Supplier Selection and Outsourcing Planning	9
Facility Location and Allocation Models	6
SC Risk Modeling	4
Replenishment Planning	4
Others	6

In 22 articles, inventory optimization models are coincided. In those models, inventory management approaches are reviewed, safety stock levels are optimized and inventory allocation among different nodes and among different level of the SC is optimized without reconfiguration of SC network. Number of articles on inventory optimization models also supports the idea that there is an increasing attention on aiming to combine inventory models and SC network optimization models.

Other three important tactical level models in the reviewed articles are “Distribution Planning and Scheduling”, “Production Planning and Scheduling”, and “Supplier Selection” Models. These results also support the idea that the tactical level SC decisions are increasingly being incorporated with the strategic level SC network models.

Other than these models, there are also other interesting tactical level SC network models coincided on the literature. Some of those are; “Product Portfolio decisions and SC network model”, “Customer Clustering Model”, “Payment Schedule Model”, and “Production facility utilization model”. In these models, how tactical level SC decisions influence SC network optimization models is also analyzed.

3.3.4. Strategic Level SC Network Optimization Models

3.3.4.1. Brief information on the reviewed models

As mentioned on the introduction of the chapter, in this section of the literature review, there is a focus on the articles with "Strategic Level SC Network models" developed recently. The models which consider the reconfiguration or relocation of the SC network nodes and arcs (0-1 decisions) are considered as "strategic level". Below on Table 3-5, please find the brief information on the journals that the articles published;

Table 3-5. Classification of the Models by Journal

Journal	# of Articles
Int'l Journal of Production Economics	19
Computers & Chemical Engineering	14
European Journal of Operational Research	12
Transportation Research – Part E	8
Computers & Industrial Engineering	6
Expert Systems with Applications	5
Computers & Operations Research	4
Decision Support Systems	2
Int'l Journal of Operations Research	1
Total	**71**

The classification of the models according to publication year is presented below on Figure 3-1;

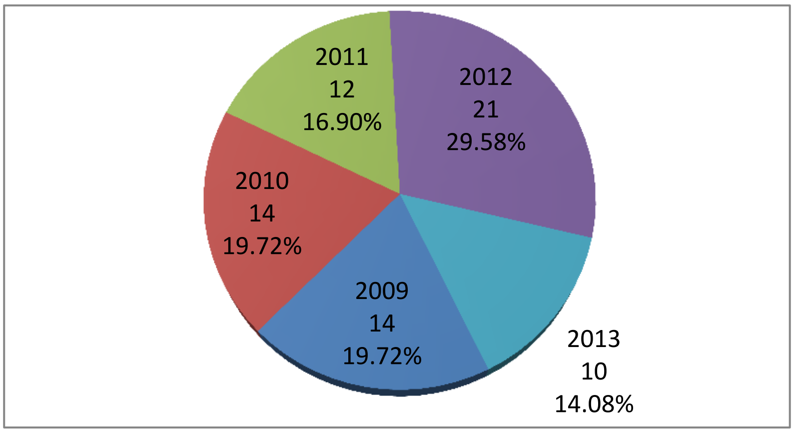

Figure 3-1. Classification of the models by publication year

A detailed list of the reviewed articles and the various features of the each model is provided on Appendix II.

3.3.4.2. Classification of the models

In the literature, there is an increasing number of studies dealing with the design problem of the supply chain networks. These studies have been reviewed by many researchers such as Beamon (1998), Meixel and Gargeya (2005), Melo et al (2009), and Tahseen and Amos (2010). In those literature reviews, the models are generally classified by different characteristics of the models such as the nature of the models (deterministic versus stochastic or mathematical models versus simulation models), performance measures used in the models and the solution algorithm used in the model. Different classifications appearing in the SC network optimization literature is summarized below;

i. Number of Period(s);
   a. One period
   b. Multi-periods
ii. Number of commodities;
   a. Single item
   b. Multiple item
iii. Model Nature
   a. Deterministic
   b. Stochastic
   c. Simulation based
   d. Fuzzy based
iv. Number of Stages - Integration;
   a. Single Stage – Simple models
   b. Multistage – Integrated models
v. Number of objective function(s)
   a. Single objective models
   b. Multi-objective models

vi. Performance Measures - Objectives

   a. Profit maximization
   b. Cost minimization
   c. Service level maximization and
   d. Other objectives

vii. Solution Algorithm

   a. Mathematical models – exact solution
   b. Generic Heuristic models such as Genetic Algorithm, Branch and Bound Algorithm, and Benders' Decomposition.
   c. Problem specific heuristic

In our detailed review, similar classification method is used to analyze and present the reviewed models.

3.3.4.3. Number of commodities and number of periods

In classical SC network optimization models, the commodities are aggregated to a single commodity to represent all commodities. However, in recent years, the number of multi commodity models has increased. Similarly, single period is classically thought to represent the long terms about which strategic level decisions are taken. Recently, multi period models have been increasingly used to represent the changes throughout the periods. Below, Table 3-6 presents a summary of the selected articles on the number of commodities and the number of periods.

Table 3-6. Multi Commodity and Multi Period Models

Type of the Model	# of Articles
Single Commodity – Single Period Models	25
Single Commodity – Multi Period Models	5
Multi Commodity – Single Period Models	15
Multi Commodity – Multi Period Models	26
Total	**71**

3.3.4.4. SC network coverage

SC Network optimization models also differ in their network coverage. There are very simple models with only two stages such as production facility and demand points (Pimentel et. al., 2013; Martinez and Zhang, 2011; Wang et. al., 2011), however, there are also very complex models covering the network from supplier to demand points including recycling centers (Yu and Nagurney, 2013; Yang et. al., 2009; Cardoso et. al. 2013; Salema et. al., 2010; Zeballos et. al., 2012; Wang and Hsu, 2010 etc.). The SC network echelons utilized in the models are presented in Appendix II, in details.

3.3.4.5. Decision variables

It is assumed that classical SC network optimization models determine the optimum location of SC nodes and the optimal product flow within the SC nodes. However, there are 23 different decision variables used in the reviewed articles. Table 3-7 depicts a list of those decision variables and the number of incidents for each decision variable in the reviewed papers;

Table 3-7. Decision Variables in Reviewed Articles

Decision Variable	# of incidents	%
Optimal product flow	69	97,18%
SC Facility Location Selection	49	69,01%
Capacity / Capacity Expansion Decision	19	26,76%
Inventory Level Decisions Inventory Policy Selection	15	21,13%
Production level (rate) decision Production Scheduling	13	18,31%
Supplier Selection	12	16,90%
Price (at final market or at each echelon)	10	14,08%
Demand Satisfaction Level Total number of Products sold	8	11,27%
Distribution Scheduling	6	8,45%
Transportation Mode Selection	5	7,04%
Network Link Capacities	3	4,23%
Outsourcing or internal production (make or buy) Production or substitution decision	3	4,23%

Decision Variable	# of incidents	%
Resource allocation	3	4,23%
Processing Technology Selection	3	4,23%
Process selection for each node	2	2,82%
Procurement scheduling	1	1,41%
Plant (Facility) Design	1	1,41%
Physical or via internet sales	1	1,41%
Freight carrier costs	1	1,41%
Vendor Contract Options	1	1,41%
Product design decision	1	1,41%
Farm planning	1	1,41%
Transport frequency selection	1	1,41%

Since facility location selection and optimal product flow decisions are the classical decision variables for SC network optimization models it is not surprising that the majority of the models (69 % and 97 % of the models respectively) include these decision variables.

The results also support that SC network optimization models are increasingly combined with tactical level decisions such as inventory optimization decisions, production scheduling, and distribution scheduling decisions. The number of incidents are 15, 13, and 6, respectively.

There are also some papers in which the price of the WIP products or finished products is utilized in their models as a decision variable. Majority of these models are “variational inequality” based models (Cruz et al.; 2011; Nagurney, 2010(a); Nagurney & Nagurney, 2012; Nagurney , 2010(b); Yamada et al., 2011 etc.). On those models, competition among SC partners is also modeled as inequality and the price at each echelon is used to reach balance among SC partners.

Another basic assumption in classical SC network optimization models is that the demand is supposed to be completely satisfied. However, recently more models (Kabak and Ulengin, 2011; Schütz et. al., 2009; Li et. al., 2009 etc.) include demand satisfaction level as a decision variable. The objective, on those models, is profit maximization and the models also try to find out the sales level or order fill rate which maximizes the profit.

3.3.4.6. *Model nature*

Most common classification method in the literature is the classification of model by the nature of the model, that is, the variables (generally demand and cost functions) are known or not. Figure 3-2 depicts the nature of the models built since 2009;

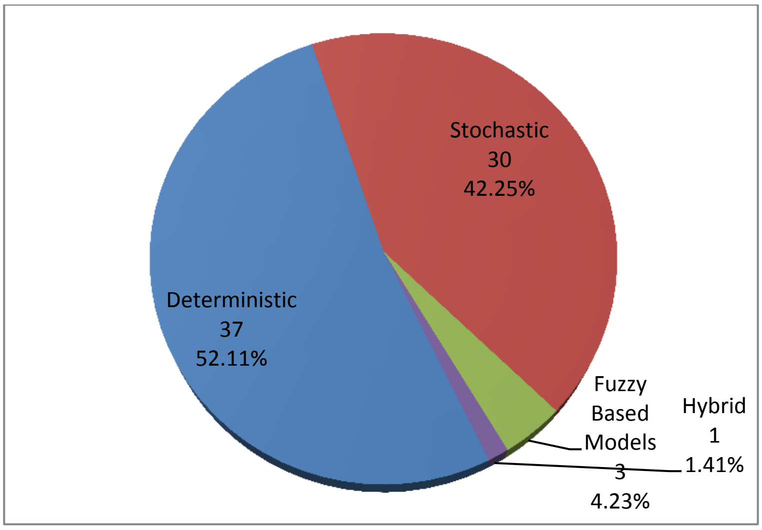

Figure 3-2. SC Network Optimization Models

3.3.4.7. *Solution methodology*

Figure 3-3 gives an overview of solution methodologies that have been utilized for solving optimization models. To classify the solution algorithms, five categories are used;

- ✓ *Exact Solution, Mathematical Models* refers to use of mathematical solutions to find the exact solutions
- ✓ *Problem Specific Heuristic solutions* include the use of specified heuristic solution algorithm specifically developed to solve the model
- ✓ *Generic Heuristic solutions* cover the use of generic solution algorithms such as branch – bound, genetic algorithms, ant colony optimization, bender's decomposition etc. The detailed information on which heuristic algorithm methods are used on which model is specified in Appendix II.

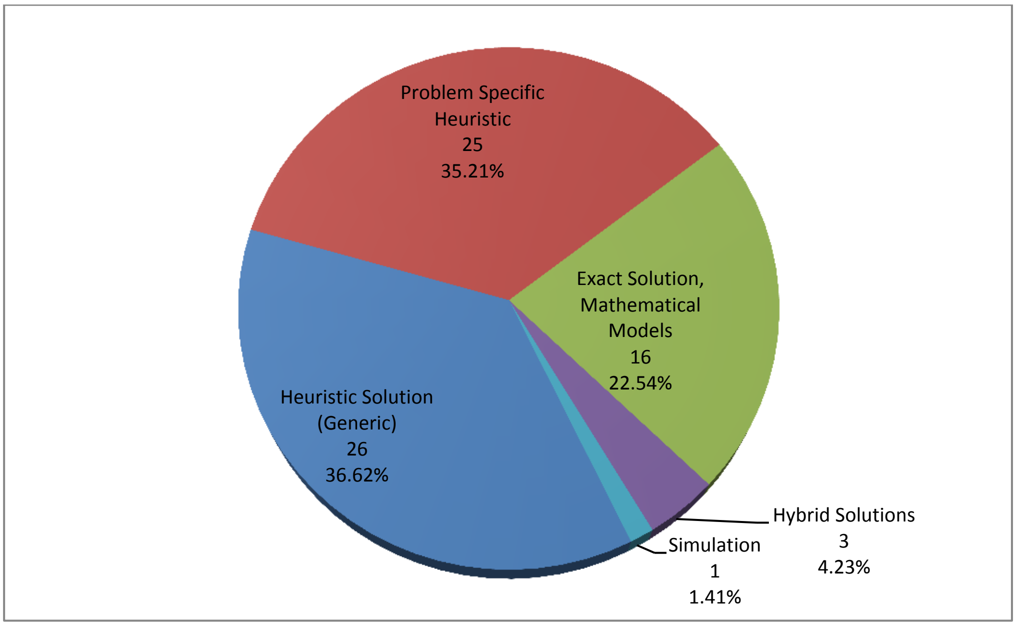

Figure 3-3. Solution approaches for SC network optimization problems

- ✓ *Simulation Algorithm* refers to use of simulation techniques
- ✓ *Hybrid Solutions include* the use of two or more algorithms together within the model

3.3.4.8. SC performance measures / objective functions

Another important characteristic of the SC network optimization models is the performance measures / objectives used in the optimization models. There are two separate approaches to categorize model objectives.

The objectives may be categorized by: (1) objectives that are based directly on cost or profit such as cost minimization, sales maximization, profit maximization, etc. and (2) objectives that are based on some measure of customer responsiveness such as fill rate maximization, customer response time minimization, lead time minimization, etc. (Beamon, 1998).

Another categorization of the model depends on the number of the objective functions utilized on the model. Therefore, in order to classify the reviewed models, three different categories are used,

- Single - Cost minimization objective
- Single – Profit maximization objective
- Multiple objective

Figure 3-4 depicts the classification of the models by the objective functions.

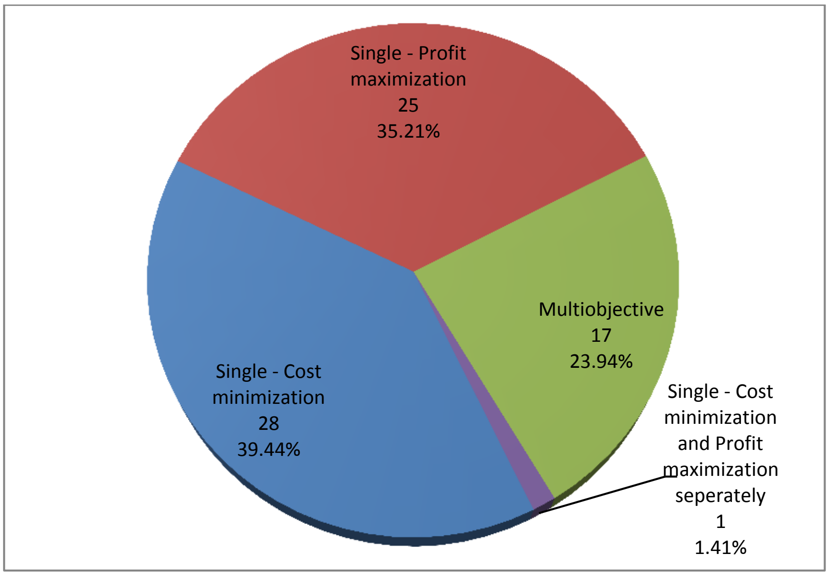

Figure 3-4. Supply Chain Network Optimization Models – Objective Classifications

Even though the majority of the papers still feature cost minimization or profit maximization objectives, it may also be concluded that there is a major shift from cost minimization objectives to profit maximization objectives compared to the figures in Melo et. al. (2009). In the literature review by Melo et. al., only 16 % of the models included profit maximization objectives, while 75 % of the models included cost minimization objectives.

Table 3-8 depicts the specific objective functions used in the models. Number of incidents for each objective is also provided on the table.

Table 3-8. SC Performance Measures

Performance Measure Category		Performance Measure	# of incidents	%
Cost Measures	59,15%	**Cost Minimization**	**39**	**54,93%**
		Minimization of the total average cost per fill demand	1	1,41%
		Spend of the buyers at each SC	1	1,41%
		Average per unit product cost	1	1,41%
Profit Maximization	43,66%	**Profit maximization**	**25**	**35,21%**
		Maximization of net present value	**6**	**8,45%**
Customer Service Related Measures	11,27%	Maximization of Fill Rate	2	2,82%
		Total Activity Days	1	1,41%
		Product quality	1	1,41%
		Transportation time	1	1,41%
		Lead time minimization	1	1,41%
		Minimization of total time	1	1,41%
		Maximization of on time delivery	1	1,41%
Other SC Measures	16,90%	Damage - overall impact factor	1	1,41%
		Risk minimization	2	2,82%
		SC Robustness	1	1,41%
		Maximization of SC Compatibility Index	1	1,41%
		Emission minimization	**4**	**5,63%**
		Minimization of environmental effect	2	2,82%
		Maximization of preferred suppliers	1	1,41%

As seen on Figure 3-4, around 24 % of the studies feature multi objective functions. However, in the literature review by Melo et. al., only 9 % of the papers feature multi-objective models. Table 3-9 depicts the changes in the percentage of the multi-objective models throughout the years.

Table 3-9. Percentages of Multi-objective Models by Year

Year	Multi-objective Models (%)
Review by Melo et. al. (Before 2009)	9.0
2009	14.3
2010	14.3
2011	25.0
2012	38.1
2013	20.0

Table 3-9 also shows that there is an increasing percentage of multi-objective models. Generally, in multi-objective models, one of the objective functions is cost minimization function, while, the other objective is customer service level, environmental effect or risk mitigation related objectives (e.g. Olivares-Benitez et. al., 2013; Shankar et. al. 2013; Akgul et. al., 2012; Prakash et. al., 2012 etc.)

The results also support the idea that optimizing single objective is not adequate when optimizing a supply chain as it is a dynamic network consisting of multiple transaction points with complex transportations, information transactions and financial transactions between entities. SC modeling is multi-objective in nature and involves several conflicting objectives, both on the individual entity level and on the supply chain level (Tahseen and Amos, 2010).

3.3.4.9. Competition within the market / Demand functions

One of the most important factors, which needs to be taken into account when designing the SC network is the existence of the competition within the market among firms providing the same or substitutable goods. If there already are other rivals in the area offering the same goods, then the new chain will have to compete for the market and the demand will be determined by the factors of that competition. Table 3-10 lists the articles which define the competition on the market to some extend or define how the demand is influenced by the competition on the market or price.

Table 3-10. Models with Demand Functions on the Market

Article	Competition / Demand Function
Cruz et al.; 2011	No competition (Demand as a function of the price)
Nagurney, 2010(a)	Yes (Oligopolistic Competition)
Yamada et al., 2011	No competition (Demand as a function of the price)
Carle et.al., 2012	No Competition (Demand as a function of marketing policy)
Yu and Nagurney, 2013	Yes (Oligopolistic Competition)
Yang et. Al., 2009	No competition (Demand as a function of the price at the market and the price at the other markets)
Cruz, 2009	No competition (Demand as a function of the price)
Nagurney and Yu, 2012	Yes (Oligopolistic Competition)
Masoumi et. Al., 2012	Yes (Oligopolistic Competition)
Zamarripa et. Al., 2012	Yes (Oligopolistic Competition)
Amaro and Barbosa-Póvoa, 2009	No competition (Demand as a function of the price)
Meng et. Al., 2009	No competition (Demand as a function of the price)

As seen on the table, there are only 5 papers modeling the competition on the market. In those papers, the demand is simultaneously modeled as a function of both the retailer's and the competitor's price (oligopolistic competition). In other models presented on the table, the demand is modeled as a function of only the retailer's price. There is only one model (Carle et. al., 2012) in which the demand is modeled as a function of selected marketing policy such as inventory-based replenishment policy, made-to-order policy or vendor managed inventory policy.

Other than the reviewed 71 articles, there are two more papers (Rezapour and Farahani, 2010; Rezapour et. al. 2011) incorporating the effects of the SC network optimization models with customer demand models. Those papers also modeled oligopolistic competition and solve it by variational inequality formulation.

In oligopolistic competition models, the authors develop an equilibrium model to design a centralized supply chain network operating in markets under deterministic price-depended demands and with a rival chain present. Competing two chains provide competitive products, either identical or highly substitutable, for some participating retailer markets. The authors model the optimizing behavior of these two chains, derive the equilibrium conditions, and establish the finite-dimensional variational inequality formulation, and solve it.

It may be concluded that, most of the models assume that the customer demand, either deterministic or stochastic, is not substantially influenced by the SC network configuration itself. However, the physical network structure of a SC completely influences its performance, and is one of the important factors impacting chain's competitiveness, especially for the retail markets. Physical network of the supply chain, specifically average distance from the customers may substantially affect the customer demand.

3.3.4.10. SC risk modeling

SC risk management is an important part of SC network configuration and optimization since it involves designing a robust SC network structure and managing the product flow throughout the configured network in a manner which enables them to be able to predict and cope with disruptions (Baghalian et. al., 2013).

The uncertainties associated with SC events such as heavy rain, excessive wind, accidents, strikes, and fires may interrupt the normal operations in SCs. In a study, Hendricks and Singhal (2005) quantified the negative effect of SC disruptions on the long – term financial performances such as profitability, operating income, sales, assets, and inventories. Therefore, SC network models have also been investigated to figure out how SC risks are quantified and affected through network reconfiguration.

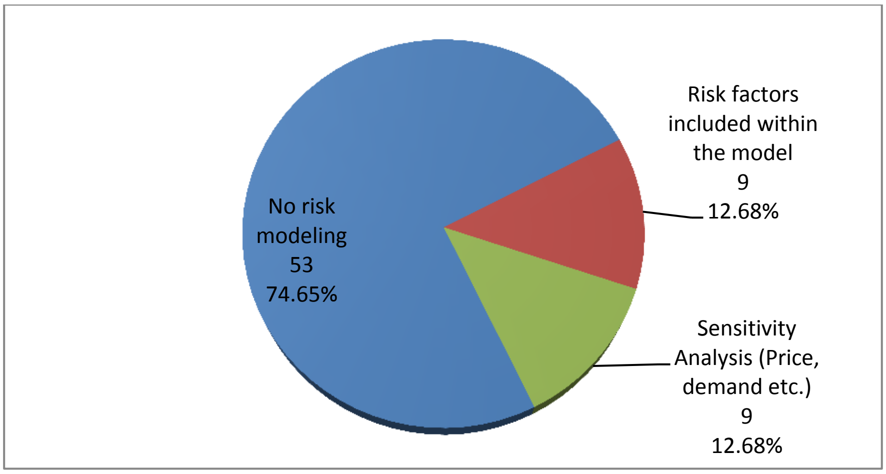

Figure 3-5. SC Risk Modeling

Figure 3-5 depicts the number of models with embedded risk modeling. Only around 13 % of the models (Cruz et. al., 2011; Baghalian et. al., 2013; Lundin, 2012; Yu and Nagurney, 2013; Cruz, 2009; Masoumi et. al., 2012; Bassett and Gardner, 2010; Pan and Nagi, 2010; Kumar and Tiwari, 2013) include SC risk modeling, defined as SC robustness, SC risk models etc. Besides that, same number of articles (Wang, 2009; Hsu and Li, 2011; Kim et. al., 2011; Li et. al., 2009; El-sayed et. al., 2010; Kostin et. al., 2011; Huang et. al., 2010; Andersen et. al., 2012; Bogataj et. al., 2011) includes some sort of sensitivity analyses on their models. These papers analyze the model's sensitivity to the changes in some parameters such as price, demand, yield rate, costs etc.

3.3.4.11. Other features of SC network optimization models.

Review on SC network optimization models is completed by providing additional information regarding "Green SC", "The Existence of Real Life Case" and "Existence of Integration among SC members". Even though, the detailed data is presented in Appendix II, three more figures are presented below to highlight some of the results.

One important topic which gained important attention recently is "Green Supply Chain". Figure 3-6 depicts the number of models including Green Supply Chain context and concerns.

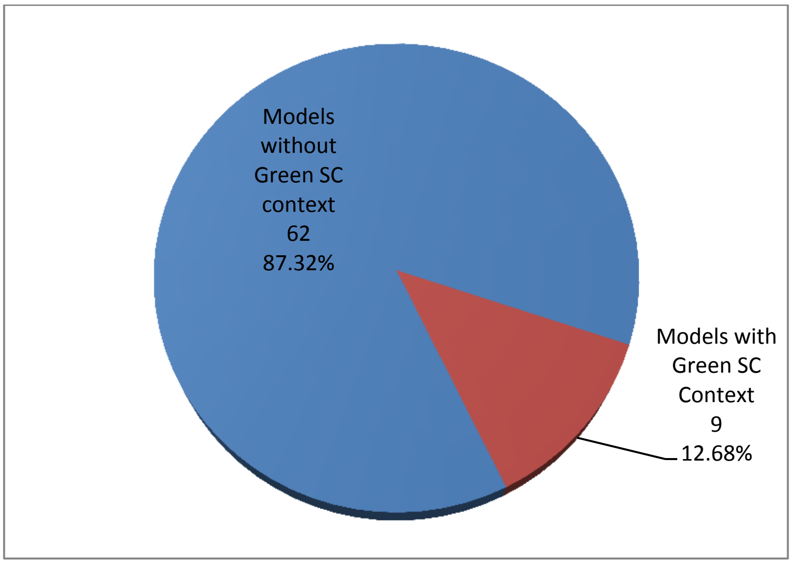

Figure 3-6. Number of Models with Green Supply Chain Context

There are only 9 models (Cruz, 2009; Bojarski et. al. 2009; Nagurney and Yu, 2012; Chaabane et. al., 2012; Akgul et. al., 2012; Pinto-Varela et. al., 2011; Wang and Hsu, 2010; Bogataj et. al., 2011; Lee and Dong, 2009) with Green Supply Chain context. In those multi-objective models, the environmental effects of SC configuration or carbon emission rates are used as one of the multiple objectives.

Another figure provided below shows the number and percentage of models which include a real life scenario on their analysis.

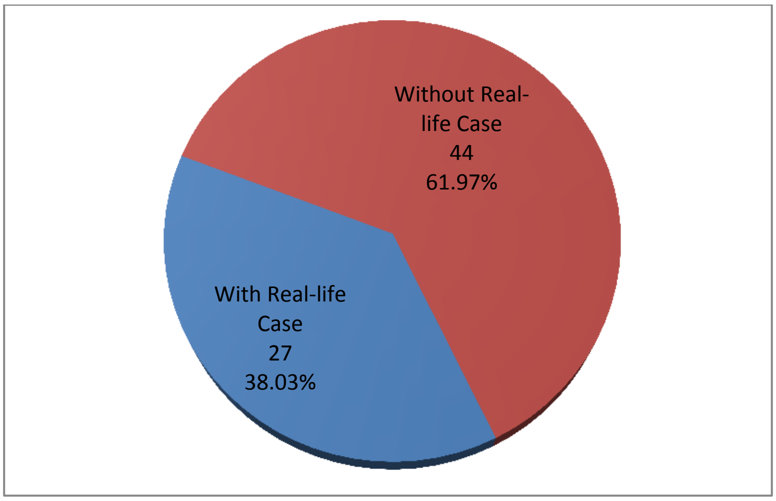

Figure 3-7. Number of Models with a real-life case

The last figure provided below presents the competition or integration among SC network members. In classical SC network optimization models, the whole chain is assumed to be fully integrated. However, in some models developed recently (Cruz et al.; 2011; Nagurney, 2010(a); Yamada et al., 2011; Nagurney, 2009; Yu and Nagurney, 2013; Yang et. al., 2009; Cruz, 2009; Chen, 2010; Amaro and Barbosa-Póvoa, 2009; Meng et. al., 2009) presented in Appendix II, the SC is assumed to be balanced among its members with a price – demand mechanisms.

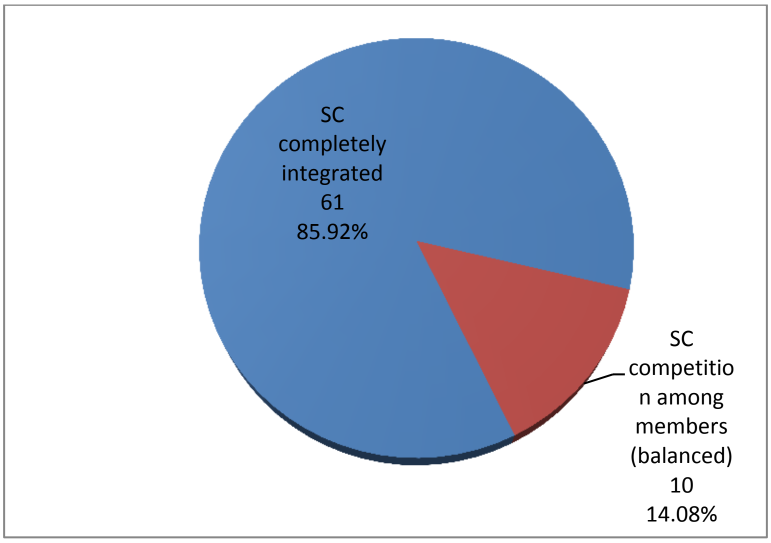

Figure 3-8. Competition among SC members

3.4. Multi Objective Optimization Models in the Literature

In this section of the literature review, a detailed literature review specifically focused on multi-objective SC network models is presented in order to guide readers on the multi-objective methods which may be utilized on the proposed model. There are several approaches utilized to handle with the multi-objectivity on SC network optimization models on the literature. Below, on Table 3-11, presents multi-objective models and lists the models utilized those approaches.

18 different models are reviewed to evaluate and summarize different multi objective approaches utilized to handle the multi - objectivity in SC network optimization models.

The basic conclusion which may be drawn from the analysis is that most common approaches utilized are basic approaches such as ε - constraint, weighted sum, and goal programming approaches. In 9 models (Sabri & Beamon, 2000; Guillen et. al., 2005; Akgul et. al., 2012; Benitez et. al., 2013; Zhang et. al., 2012; Bojarski et. al., 2009; Varela et. al., 2011; Nepal et. al., 2012; Osman & Demirli, 2010) out of 18 models, those kind of approaches are basically utilized to convert multi-objective models into one single objective models.

Another finding of the review of multi objective models is that, in 3 models (Cruz & Liu, 2011; Nagurney & Yu, 2012; Pan & Nagil, 2010), one of the objectives is directly added to the cost factor as penalty fees. Therefore, again, the models are converted to single objective models.

In other 3 models (Chaabane & Paquet, 2012; Zamarripa et. al., 2012; Costantino et. al., 2009), the models are run with all alternatives to present the all results to the decision maker and to show how multiple objectives change through alternatives instead of converting objectives into one single objective and find the mathematically optimal solution. In those models, the alternatives are limited, therefore, all solution set is provided to the decision makers (DMs).

Table 3-11.Multi-objective Models Summary – Multi-objective Solution Approaches

Model	Number Of Objectives	Objectives	Multi-objectivity Solution Approach	Explanation
1. (Sabri & Beamon), 2000	Bi-objective	1. Cost Minimization 2. Flexibility Maximization (W)	ε – Constraint	W > ε is set to a predefined value then relaxed iteratively.
2. (Guillen et. al.), 2005	Multi-objective	1. Maximization of Net Present Value (NPV) 2. Maximization of Demand Satisfaction (MDSat) 3. Minimization of Fin. Risk (DRisk)	ε - Constraint	MDSat > ε_1 and DRisk > ε_2 is set and maximization problem is solved.
3. (Akgul et. al.), 2012	Bi-objective	1. Min. of Total Daily Costs (TDC) 2. Minimization of Total Environmental Index (TEI)	ε - Constraint	TEI > TEI(max) – Allowable legal limit Then minimization problem is solved.
4. (Benitez et. al.) , 2013	Bi-objective	1. Minimization of Total Costs 2. Minimization of longest transp. time from plants to customers	ε - Constraint	Different ε values are used to generate efficient set for different objective values
5. (Zhang et. al.) , 2012	Bi-objective	1. Minimization of SC Costs 2. Minimization of weighted activity days (Lead time + Production times)	Weighted sum method	Objectives are rescaled first and then weighted as ($w_1 + w_2 = 1$)
6. (Bojarski et. al.), 2009	Multi-objective	1. Min. of Damage Categories Impact 2. Min. of overall impact factor 3. Maximization of NPV	Weighted sum method Pareto optimal selection	Impact objectives are weighted and converted to the single obj. Then each scenario is run to optimize NPV. Impact factor is observed.
7.(Varela et. al.), 2011	Bi-objective	1. Profit maximization 2. Minimization of Environmental impacts	Weighted Objective & Symmetric Fuzzy Linear Programming	Relative importance of the various envt.l obj.s are converted into single obj. A fuzzy model is built. Upper and lower bounds of the model are the max. and min. for obj.s.
8. (Cruz & Liu), 2011	Bi-objective	1. Profit Maximization 2. Risk Minimization	Conversion to the single objective	One objective factor is defined as «Profit – Risk»
9. (Nagurney & Yu), 2012	Bi-objective	1. Profit Maximization 2. Emission Minimization	Conversion to the single objective	Emission is added to the cost function (multiplied by w_i : the price the firm willing to pay for each unit)
10.(Pan & Nagil), 2010	Multi-objective	1. Total Cost Minimization 2. Cost variability minimization 3. Unmet demand minimization	Conversion to the single objective	2nd and 3rd objectives are added to cost minimization function as penalties
11.(Nepal et. al.), 2012	Bi-objective	1. Minimization of Total SC Costs 2. Maximization of SC Compatibility Index	Goal Programming	Objectives are weighted. Target values are set for each objectives Minimization function is formulized
12.(Osman & Demirli), 2010	Multi-objective	1. Rate of materials assigned to reliable suppliers (maximization) 2. The raw materials from preferred suppliers (maximization) 3. Minimization of Total Costs	Goal Programming	Minimizing the deviations from the targets (Z1, Z2, Z3)
13.(Chaabane & Paquet), 2012	Bi-objective	1. Minimization of Total Costs 2. Minimization of Carbon Emissions	Alternative scenario analysis	Model optimized as a Total Cost min. function. In different scenarios the carbon emissions are observed
14.(Zamarripa et. al.) , 2012	Bi-objective	1. Min. of Total Operating Costs 2. Min. of the expenses at each SC	Alternative scenario analysis	Cooperative and non-coop. scenarios are run and the results observed
15.(Costantino et. al.), 2009	Multi-objective	1. Cost Minimization 2. Quality Maximization 3. Transportation Time minimization	Alternative Scenario Analysis	Each alternative solution is run to generate pareto optimal solution set. Then DM need to make evaluation.
16.(Shankar et. al.), 2013	Bi-objective	1. Minimization of Cost 2. Max. of fulfilled customer demand	Genetic Algorithms to generate Pareto optimal solution set	Evolutionary algorithm is used to generate pareto optimal solution set.
17.(Martinez&Zhang), 2011	Bi-objective	1. Minimization of Total Cost 2. Minimization of Lead Time (LT)	Genetic Algorithms to generate Pareto optimal solution set	Pareto optimal set is generated through Ant Colony Optimization Algorithm
18.(Prakash et. al.), 2012	Bi-objective	1. Minimization of Total Average Cost per Filled Demand 2. Maximization of Demand Fill Rate	Genetic Algorithms to generate Pareto optimal solution set	Pareto optimal front achieved by Knowledge Based GA

Only in 3 models (Shankar et. al., 2013; Martinez & Zhang, 2011; Prakash et. al., 2012), evolutionary algorithms are utilized to successively determine pareto-optimal solution set. Determination of the optimal solution set is totally dependent on the subjective comparisons among model objectives. Therefore, all the break points among various objectives, within the model, are explored and presented to DMs to support the decision making.

3.5. Brief Summary of the Literature Review and Suggestion for the Development of a New Model

One of the major conclusions that can be drawn from the literature review is that many relevant tactical/operational level decisions in SCM, such as procurement planning, production scheduling, distribution scheduling, the choice of transportation modes, inventory optimization decisions, and competition decisions are being increasingly integrated with Supply chain network optimization decisions.

Another conclusion of the literature review is that, recently, the number of non-deterministic models is increasing even though majority of the models are still deterministic in nature.

While reviewing the SC network models it may be easily noticed that the models most differ in the solution methodology used to solve the models. One third of the models have been solved by specifically developed heuristic based algorithms; and more than one third of the models used generic heuristic algorithms (genetic algorithms, branch and bound, ant colony optimization etc.). About one quarter of the models use mathematical models to find exact, optimal solutions.

Another major conclusion which may be drawn from the literature is that only around 24 % of the models are multi – objective even though the SC networks are multi objective in their nature.

Maybe the most important conclusion which may be drawn from the literature is that almost all of the literature on SC network modeling assumes that the customer demand, either deterministic or stochastic, is not substantially influenced by the SC network itself as illustrated on the below table . However, the physical network structure of a SC completely influences its performance, and is one of the important factors impacting chain's competitiveness, especially for the retail markets.

Table 3-12. Models with Demand Functions on the market compared with proposed model

Article	Competition / Demand Function	Demand Functions	Demand Function Including SC Network Decisions
Cruz et al.; 2011	No competition	Price	No
Nagurney, 2010(a)	Yes (Oligopolistic Competition)	Price Competitor's Price	No
Yamada et al., 2011	No competition	Price	No
Carle et.al., 2012	No Competition	Marketing Policy	No
Yu and Nagurney, 2013	Yes (Oligopolistic Competition)	Price Competitor's Price	No
Yang et. al., 2009	No competition	Price at the market Price at the other market	No
Cruz, 2009	No competition	Price	No
Nagurney and Yu, 2012	Yes (Oligopolistic Competition)	Price Competitor's Price	No
Masoumi et. al., 2012	Yes (Oligopolistic Competition)	Price Competitor's Price	No
Zamarripa et. al., 2012	Yes (Oligopolistic Competition)	Price Competitor's Price	No
Amaro and Barbosa-Póvoa, 2009	No competition	Price	No
Meng et. al., 2009	No competition	Price	No
Rezapour and Farahani, 2010	Yes (Oligopolistic Competition)	Price Competitor's Price	No
Rezapour et. al., 2011	Yes (Oligopolistic Competition)	Price Competitor's Price	No
Proposed Model	**No Competition**	**Price and Attraction Function**	**Yes**

In order to cover the gap in the current SC network literature, a model incorporating competitive facility location problems and SC Network optimization problems modeling how the changing demand, dependent on not only price also customer service related functions will affect the strategic level SC network configuration decisions is proposed.

As explained in the detailed literature review, SC networks are multi objectives in their nature. Therefore, the proposed model will be defined as multi objective and will be applied to a real – life problem. The objectives are; profit maximization, demand maximization and SC risk minimization. Cost minimization or profit maximization are traditional objectives in SC network optimization problems. Besides, profit maximization, objective of the demand maximization is also utilized within the model since the model company also aims to increase its sales by reconfiguration of its SC network and maybe by opening new Distribution Center(s). Third objective defined in the proposed model is risk minimization function. Since SC risks have enormous effect on the long – term and short term SC and financial performance of the companies (Hendricks and Singhal (2005), in every strategic level SC network decisions need to be modeled to understand how the decision influences SC risks.

The main contribution of the proposed model to the literature would be incorporating the changes in the demand, which is subject to the both price and distance from the end-customers and which is substantially influenced by strategic level SC network model decisions, to Supply Chain Network Optimization models. This model will also be the first model utilizing supply side risk analysis, demand functions and strategic level SC decisions. As explained in the literature review of multi-objective models, there are, in fact, many multi-objective SC network optimization models; however, just a few of them include SC risks as one of its objectives.

CHAPTER 4. COMPETITIVE FACILITY LOCATION PROBLEMS

As mentioned in Chapter 3, one of the important outcomes of the literature review is that almost all of the SC network optimization studies ignore the impact of strategic level SC decisions on the competition, and eventually the demand. However, in real life problems, demand is one of the most important factors being affected by the physical location decisions (SC reconfigurations). That is why, in this chapter, facility location problems, specifically, so called "Competitive Facility Location Problems" will be introduced. The chapter will start with a brief introduction of the definition of "facility location problems" and "competitive facility location problems". After these definitions, how the demand on competitive facility location problems is modeled is briefly explained. Then the literature review on those models is presented. The chapter ends with a brief conclusion of the chapter.

4.1. Facility Location Problems

Facility location problem is one of the oldest decision making problems in history, considered to be a one-hundred year old science. Some experts believe that facility location as a classic science, has originated from Pierre de Fermat, Evagelistica Torricelli (a student of Galileo), and Battista Cavallieri. It is said that these people independently proposed the basic Euclidean spatial median problem early in the seventeenth century; but formally it is accepted by all scientists that Alfred Weber's book (A. Weber, Uber den Standort der Industrien, Tubingen. Theory of the Location of Industries, University of Chicago Press, 1909) is the starting point in the history of location science (Farahani et al. 2009).

A general facility location problem involves a set of spatially distributed customers and a set of facilities to serve customer demands. In facility location problems, these questions are to be answered:

(i) Which facilities should be used (opened)?

(ii) Which customers should be serviced from which facility (or facilities) so as to minimize the total costs?

In addition to this generic setting, a number of constraints arise from the specific application of the problems (Melo et al., 2009).

4.2. Competitive Facility Location Problems

Most of the facility location researches have been built around the modeling assumption of a monopoly: the facility to be located offers a unique product or service and is the single player in the market. However, there are also some models incorporating the demand on the market since most situations, in practice, do not fit such models. A facility location model is said to be about competitive when it incorporates the fact that other facilities are already (or will be) present in the market and that the new facility(ies) will have to compete with them for its (their) market share (Plastria, 2000).

Competition is also classified according to competition nature of the market. According to Plastria’s (2000) classification, there are three types of competition;

a) Static competition: This is the simplest competition category. In this kind of competition, new entrant rival knows the characteristics of the competition and the competition is assumed to be fixed.
b) Competition with foresight: Rivals are not present in the market yet but they will enter soon afterwards.
c) Dynamic competition: Existence of Nash equilibriums in a scenario described as a game, in which rivals simultaneously compete in prices, locations, qualities, etc.

4.3. Demand Function in Competitive Facility Location Models

In competitive facility location models, the customer demand is assumed to be elastic, expanding as the utility (attraction) of the service offered by the facilities increases. Increases in the attraction may be achieved by the increasing number of facilities or locating facilities closer to the customer (Aboolian et al. 2007).

In order to model the market share of the facility, the way customers behave when making the choice between competing products need to be modeled. This will largely be determined by the product type and the market characteristics. It is considered that customers feel some attraction towards each of the competing products. The attraction function (also called utility function) describes the customer's attraction (Plastria, 2000).

In attraction function, the customer demand is assumed to be elastic, expanding as the attraction of the service offered by the facilities increases. Increases in the attraction may be achieved by the increasing number of facilities or locating facilities closer to the customer (Aboolian et al. 2007).

Traditionally, it is considered that, the price determines the customers' choice and eventually the demand. However, the customer should travel to the facility and the travel cost need to be included in the cost. Other than price or the total cost of the product, there are some other factors such as availability of the product, total waiting time, publicity etc. which also substantially influenced by location decisions need to be included in the attraction functions (Plastria, 2007).

One of the main objectives in competitive facility location models is the maximization of the total market share. This is the sum of the total demand which will be served by the facilities. In most of the models, the objective is expressed as the profit maximization which helps to adequately measure the cost / benefit trade-offs in the design alternatives (Plastria, 2007).

4.4. Literature Review

There is growing number of researches on competitive facility location models. Only a few of them are briefly summarized below in order to specify different characteristics of the different researches.

In 2002, Nagurney et. al. proposed variational inequality (VI) model to optimize SC network. In variational inequality models, the supply chains are defined as non-cooperative. The model studied the equilibrium condition of the SC and simultaneously studied the behaviors of the decision makers. In the model, Nash game – theoretic approach is utilized to quantify the competition. The consumption behavior of the consumers (utility / attraction factor) is characterized by the price.

One of the recent researches on competitive facility location models is by Boyaci and Gallego (2004). The authors consider a market with two competing SCs, each consisting of one wholesaler and one retailer. In the study, it is assumed that the environment forces SCs to charge similar prices and to compete strictly on the basis of customer service. They model customer service competition using game-theoretical concepts. They consider three competition scenarios between the SCs.

- ✓ Uncoordinated scenario; individual members of both SCs maximize their own profit by individually selecting their own service and inventory policies
- ✓ Coordinated scenario; wholesaler and retailer of each SC coordinate their service and inventory policy to maximize the profit of the SC.
- ✓ Hybrid scenario; the competition is between one coordinated and one uncoordinated SCs.

The authors compare the results of each scenario and find that the coordination is a dominant strategy for both SCs and SCs are often worse off under the coordinated scenario. The consumers are the only guaranteed beneficiaries of coordination.

Aboolian et. al. (2007) considers the problem of simultaneous optimization of location and design for a set of new facilities that will compete for customer demand with each other, as well as with some pre-existing facilities controlled by the competitors. Their model (called Competitive Facility Location and Design Problem) considers a spatial interaction model with multiple facilities.

They assume a discrete facility location framework: customer demand is assumed to originate from a finite number of customer nodes and there is a finite set of potential facility locations. The customer demand is assumed to be elastic, as the attraction of the service offered by the facilities increases. Market share attraction model is utilized to split the demand among facilities. Attractiveness does not only depend on the number and the location of the facilities but also size, appearance, accessibility, layout, product variety etc. of the facilities.

Zhang and Rushton (2008) developed a model for locating service site in the context of locating bank branches. In the proposed model, the customers make their choices according to attraction function among available alternative facilities. The objective of the model is to maximize consumer attraction subject to constraints such as queuing time and budget of multi-site facility owners. Their model has five important characteristics;

- First, the model takes not only distance but also attractiveness function into account while customers select in competing service sites.
- In the model, the authors assumed that other organizations are assumed to exist and make no changes in size and locations.
- The size of each facility is determined by the model. Ideally, the larger the facility, the more attractive it will be.
- The model also considers queuing time.
- The closing and opening of facilities are considered simultaneously and subject to budget constraint.

Rezapour and Farahani (2010) developed an equilibrium model to design centralized SC network in the presence of a rival chain. They assume the competing chains provide competitive products for some retail markets. Their model also considers the impacts on the strategic facility location decisions on the tactical inventory and shipment decisions. In the model, each market has a deterministic price – dependent demand. However, their model ignores attraction functions other than price such as closeness to customers, which is substantially influenced by the location decisions, in their demand function.

Even though competitive facility location models may have some characteristics of SC networks and analyze the rival chains existing in the market, they model only distribution part of the SC. That is, these models ignore some crucial characteristics of SC Network models, such as product flows, production facilities, transportation modes, suppliers etc. On the other hand, for the sake of simplicity almost all of the Supply Chain Network Models ignored the competition within the market.

Therefore, the conclusion which can be drawn is that the concept of SC network optimization modeling needs to be simultaneously utilized with competitive facility location models in order to model the competition within the market to have clear grasp of the demand.

CHAPTER 5. THE PROPOSED MODEL AND ITS APPLICATION

In this chapter, the proposed model will be defined and it will be applied to a real life problem in order to present the applicability of the model. In the first section of the chapter the proposed model and the mathematical notations and formulations of the model is presented in details. In the next section of the chapter, the real life problem of the model company is defined and how the proposed model is applied to real life scenario is briefly explained. After the real –life scenario definition, the model results are presented and discussed. Then, sensitivity of the model results with respect to the several parameters is analyzed and presented.

5.1. The Proposed Model

In that section of the chapter, the proposed model is presented in details. At the end of the section, notations and formulations of the mathematical model are provided.

5.1.1. Model Overview

The model is built as MILP with three echelon SC network, with multi products, and single period.

Objective of The Model: Optimization of the SC Configuration and analyze how the location and the number of the DCs will influence the SC performance metrics.

Model Nature: Model nature is deterministic. The unique unknown variable within the model is the demand. The demand at each customer zone is assumed to be determined by the price and the attraction level defined as DC - one day transportation coverage availability.

5.1.2. SC Network

The SC structure consists of three echelons.

(1) Suppliers: The merchants are supplied by several suppliers. The model defines which types of products are supplied by which suppliers by predefined rates. Since the objective of the model is not to optimize supplier selection decisions, supplier rates are used for each product type.

(2) Distribution Center: Within the proposed model, all products are distributed to customer zones through DC(s).

(3) Customer Zones: Customer zones are defined as final points for products. Those points are also defined with their demand definitions.

5.1.3. Model Objectives

As explained in literature review section, SC networks are multi - objectives in their nature. Therefore, the proposed model is built as multi objective. There are three objectives defined in the proposed model;

- Objective 1: Maximization of the total profits. Profit is calculated by the subtraction of the total costs from the total revenue
- Objective2: Maximization of the total sales; dependent on the price and the distance between DC and the customer zone. The sales volume is also influenced by the probability of SC disruption through lost sales volume. The sales volume is not calculated as sum of the total products distributed to customer zones since the model may choose not to fill some of the demand when it is not profitable.

- Objective 3: Minimization of SC Risk: Path based SC risk formulation is utilized. The objective is defined as the maximization of the Risk Value. Risk value calculation is defined under the heading of "Risk Function" in details.

A multi-objective problem arises in the model, due to multiple objectives defined above. A multi-objectivity solution approach needs to be utilized to solve the multi-objectivity.

5.1.4. Products

The model is defined as multi product. The products are aggregated to limited number of products to represent whole product mix.

5.1.5. Demand Function

In SC network modeling literature, the demand are generally either defined as deterministic or defined as product of the price. Since the main purpose of the study is to prove that adding attraction function, which is also impacted by strategic level SC decisions, to the demand model may have substantial influence on SC network optimization decisions, the demand model is built to include both price elasticity and attraction function. The demand is defined as product of both the sales price and also the responsiveness of the SC network in terms of the distance between DC and Customer Zones. In spite of more complex and comprehensive demand model, a simple model is developed since a simple model including price change and a kind of attraction function is good enough to capture the impacts of the attraction function on the demand.

Model firm operates in a competitive environment. According to "Law of Demand", the price of the product and the quantity demanded are inversely related. That is, as the price of a good rises (falls) and all other things remain constant, the quantity demanded of the good falls (rises) (Baye M. R., 2010). In this work, a deterministic approach is utilized to explain the demand pattern of the products. The model considers the market price as the core explanatory to the demand pattern.

It is also recognized that there are also some other variables which influence the demand. These variables are known as *demand shifters*. Demand shifters may be "consumer income", "prices of related goods", "advertising", and "consumer expectations" (Baye M. R., 2010) Since, in our model, it is claimed that the closeness of the Distribution Center to the retail outlet have an impact on the demand, our demand function will also include the distance function between DC and the retail outlets. In summary, our demand function will include two independent variables;

- Demand to Price elasticity coefficient (α); is a general economical concept defined as the absolute value of the logarithmic derivative of demand to price (Gujarati, 1999). In the model, the price elasticity is utilized to define the demand change from the base demand.
- Availability of one – day replenishment coverage affect (β); At customer locations, especially in retail business, it is really important to provide, within the short period of time, the right product to the customers who would like to buy different color or size of the products. In the proposed model, it is assumed that, in case, the distance between DC and retail outlet is less than a specified distance the right product will be provided from the DC in one day. Therefore, that will have a positive impact on the sales of the products by a predefined coefficient (β).

The demand function for a specific market and product is defined as follows;

$$\text{Demand} = (\text{Base Demand}) - [(\alpha*(\text{Price} - \text{Base Price})*\text{Base Demand})/\text{Base Price}] + \beta*\text{OneDayReplenishmentCoverage}*\text{Base Demand} \quad (5.1)$$

There is no unique and defined "α and β values" which can be used in the model. The "α and β values" depend on the characteristic of the products / services and the market conditions. Therefore, the sensitivity of the overall SC performance to "α and β values" need to be analyzed. Besides that, in order to analyze how demand changes according to the SC configuration decisions, alternative scenarios for different values of price changes are defined.

5.1.6. Risk Function

As briefly explained in the literature review section, SC network configuration decisions have substantial effect on SC risks and SC risks have substantial effects on financial and SC performances of the firms. Therefore, in our proposed model, supply side SC risk function is also defined and measured as one of our model objectives in order to analyze impact of strategic level SC decisions on SC risks.

In order to formulate SC risks, a path based formulation, as proposed by Baghalian et. al. (2013) is utilized. In path based formulation, possible disruptions in DCs (DC operations), inbound and outbound connecting links (transportation links) are considered and formulated as the probability of occurrence of the disruptions in SC network nodes and links. Instead of utilizing path based formulation, predetermined disruption probabilities for whole supply side chain may also be utilized within the model. Even though the results do not change, path based formulation help analyzer to visualize impacts of the partial disruption cases. Path based formulation also helps modelers to generalize the model with more or less connecting links etc.

Predetermined probabilities of disruptions at DCs (DC operations), inbound and outbound connecting links (transportation links) are formulized in risk value calculations. According to path-based supply side risk calculation, SC Risk value of current SC network is calculated as follows;

$$\text{SC Risk Value} = (1-\mu)*(1-\delta)*(1-\varphi)=0{,}995*0{,}99*0{,}98=0{,}965 \quad (5.2)$$

First term in the formulation is the probability of transporting the required goods without any disruptions from suppliers to DC. μ stands for the probability of disruption and assumed to be 0.5 % in base scenario.

Second term in the formulation is the probability of handling goods at DC without any disruptions. δ stands for the probability of disruption at DC operations and assumed to be 1 % in base scenario.

Third term in the formulation is the probability of transporting the required goods without any disruptions from current DC to customer zones. φ stands for the probability of disruption and assumed to be 2 % in base scenario.

In case, more than one DCs are utilized within the SC network, probability of disruption occurrences at nodes and links are assumed to be same. However, the SC risk value need to be calculated as there are more alternative DCs and links to be utilized to handle and transport the goods to the customer zones. In the formulation it has been assumed that, in case disruption occurs at any single transportation link or DC, the goods may be transported through other nodes or links. That is, the disruption occurs at the SC network only if all alternatives at any single node or echelon are disrupted. The proposed formulation to be used is as follows;

$$\text{SC Risk Value} = (1-\mu) * (1-\delta) * (1-\varphi) * O1 + (1-\mu*\mu) * (1-\delta*\delta) * (1-\varphi*\varphi) * O2 + (1-\mu*\mu*\mu)*(1-\delta*\delta*\delta)*(1-\varphi*\varphi*\varphi)*O3 \quad (5.3)$$

O1 “1”, if Only one DC is open; otherwise “0”

O2 “1”, if two DCs are open; otherwise “0”

O3 “1”, if three DCs are open; otherwise “0”

5.1.7. Cost Parameters

Total supply chain costs include different cost parameters; unit product costs, inbound and outbound transportation costs, fixed facility (DC) costs, inventory costs, and lost sales (disruption) costs.

Unit product costs; calculated as the unit costs multiplied by sales volume of each product type. Products are assumed to be supplied from suppliers with the same price; that is, the price is not subject to change according to the supplier.

Transportation costs; there are two separate transportation cost items defined within the model;

Inbound transportation costs; the costs of the transportation of products from suppliers to DCs;

Outbound transportation costs; the cost of the transportation of products from Distribution Centers to retail outlet locations

Facility costs; there are also some fixed costs for the facilities. Within model, fixed costs are defined only for DCs.

Inventory costs; within the SC network, there are also incurring inventory costs which need to be modeled. Depending on the number of the DCs utilized within the model, inventory holding costs per sold item also change.

Disruption costs; when the SC network does not operate due to disruptions, there will also be a loss of sales. Therefore, shortage costs for each product type are also defined in the model. Shortage costs are defined as net difference between sales price and the unit cost of the product. Disruption costs are calculated as the total sales times disruption probability of the whole SC network multiplied by shortage costs.

5.1.8. Decision Variables;

There several decision variables which need to be determined by the model for each price change scenario:

- Number of DCs and their locations: As mentioned above, main objective of the model is to analyze how its total profit, sales volume, and SC risks change when the company adds one or two more distribution centers to the its SC network.

- Capacity of DCs: In case, one or more DCs are opened, how much capacity needs to be allocated to each DC?

- The inbound and outbound traffic network; since there is a DC eligibility constraint, that is; a specific customer zone is supplied by a single distribution center for all kinds of product types.

- DC – Customer Zone Allocation: In case, there are more than one DCs on the network, which customer zone will be replenished by which DC need to be decided.

- Fill Rate: When the problem is defined as profit maximization problem, the model may choose to fill all the demand on the network when it is not profitable.

5.1.9. Notations and Formulation for the Model

5.1.9.1. Notations

Indices

i	Products, $i=1,\dots\dots.I$
j	Product suppliers, $j=1,\dots\dots.J$
k	Distribution Centers, $k=1,\dots\dots.K$
z	Demand Zones, $z=1,\dots\dots Z$
m	Number of DCs, $m=1,\dots\dots M$
n	Alternative Cities, $n=1,\dots.N$

Inputs

F_k	Fixed Costs for DC k
C_k	Capacity for DC k
TI_{ijk}	Inbound Transportation Cost for product (i) from supplier (j) to DC (k)
TO_{ikz}	Outbound transportation cost for product (i) from DC (k) to Customer zone (z)
IC_{mi}	Inventory costs per item in case of m DC(s)
U_i	Unit Purchasing Cost of the Product (i)
S_i	Shortage Cost of the Product (i)

SR_{ij} Supply rate for the product i from supplier j

α Price elasticity coefficient

β One Day Replenishment Coverage Area elasticity coefficient

μ Probability of disruption at the transportation link from suppliers to DC(s).

δ Probability of disruption at handling goods at DC(s).

φ Probability of disruption at the transportation link from DC(s) to Customer zones

P_{0i} Base (current) Price of product (i)

DCK_{kz} "1", if the distance between DC k and customer zone z is less than 600 km.; otherwise "0"

D_{0iz} Current demand of product (i) at customer zone (z)

DC_{nk} "1", if DC k is at City n; otherwise "0"

Outputs - Decision Variables

X_{ikz} Total number of product i distributed from DC k to Customer zone z

Y_{ijk} Total number of product i distributed from supplier j to DC k

D_{iz} Demand of product i at customer zone z

TIC Total Cost of inventory (changes depending on the total sales and the number of DCs within the SC network)

LS Total Lost Sales

LSC Total Lost Sales Costs

W Total Profit

A Total Sales

B SC Risk Value

Binary Variables

DC_k "1", if DC i is open; otherwise "0"

DCS_{kz} "1", if DC k serves Customer Zone z; otherwise "0"

O_m "1", if Only m number of DC(s) is / are open; otherwise "0"

5.1.9.2. Formulation

Objective 1: Maximization the Total Profit

$$W = [(\sum_i P_i * \sum_{kz}(X_{ikz}) - LSC)] - [\sum_i (\sum_{kz}(X_{ikz}) * U_i)] + [\sum_{ijk}(Y_{ijk}) * (TI_{ijk})] + [\sum_{ikz}(X_{ikz}) * (TO_{ikz})] + [\sum_k (F_k) * (DC_k)] + [TIC] \quad (5.4)$$

Objective 2: Maximization of Total Sales

$$A = \sum_{ikz}(X_{ikz}) - LS \quad (5.5)$$

Objective 3: Maximization of SC Risk Value

$$B = \sum_m (1 - \mu^m) * (1 - \delta^m) * (1 - \varphi^m) * S_m \quad (5.6)$$

Subject to:

$$D_{iz} = D0_{iz} + \alpha * [(P_i - P0_i) * \frac{D0_{iz}}{P0_i} + \beta * \sum_k DCS_{kz} * DCK_{kz} * D0_{iz} \quad \forall\, i, z \quad (5.7)$$

$$\sum_j Y_{ijk} \leq \sum_z X_{ikz} \quad \forall\, i, k \quad (5.8)$$

$$\sum_k X_{ikz} * DCS_{kz} \leq D_{iz} \quad \forall\, i, z \quad (5.9)$$

$$\sum_k Y_{ijk} = \sum_{kz} X_{ikz} * SR_{ij} \quad \forall\, i, j \quad (5.10)$$

$$\sum_{ij} Y_{ijk} \leq DC_k * C_k \quad \forall\, k \quad (5.11)$$

$$\sum_{k} DCS_{kz} = 1 \qquad \forall z \tag{5.12}$$

$$X_{ikz} \le DCS_{kz} * 100000000 \; \forall \; i, k, z \tag{5.13}$$

$$\sum_{k} DC_k = \sum_{m} O_m * m \tag{5.14}$$

$$\sum_{m} O_m = 1 \tag{5.15}$$

$$\sum_{i} (\sum_{kz} X_{ikz} * IC_{mi}) - TIC \le 1000000000 * (1 - S_m) \qquad \forall m \tag{5.16}$$

$$[(\sum_{i} S_i \sum_{kz} X_{ikz}) * (1 - \mu^m) * (1 - \delta^m) * (1 - \varphi^m)] - LSC \le 1000000000 * (1 - S_m) \; \forall m \tag{5.17}$$

$$[\sum_{ikz} X_{ikz} * (1 - \mu^m) * (1 - \delta^m) * (1 - \varphi^m)] - LS \le 1000000000 * (1 - S_m) \quad \forall m \tag{5.18}$$

$$\sum_{k} DC_{nk} * DC_k \le 1 \qquad \forall n \tag{5.19}$$

$$X_{ikz}, Y_{ijk}, D_{iz} \ge 0 \; \forall \; i, j, k, z \tag{5.20}$$

$$DC_k, DCS_{kz}, O_m = 0 \; or \; 1 \; \forall \; k, z, m \tag{5.21}$$

The first objective function (W) (equation 5.4) maximizes total profit and divided into five components: (1) lost sales costs excluded Total revenue, (2) Total purchasing costs , (3) Total inbound transportation costs from suppliers to DCs, (4) Total outbound transportation costs from DCs to customer zones, (4) Fixed costs associated with DC operations, (5) Total Inventory Costs.

Second objective function (A) (equation 5.5) maximizes total sales excluding total lost sales due to disruptions. Third objective function (B) (equation 5.6) maximizes SC Risk value, which is a function of disruption probabilities at SC nodes and links.

Equations 5.7 – 5.19 of the model represent, respectively:

- Eq. 5.7 specifies the demand for each customer zone for each product.
- Eq. 5.8 ensures that any product transferred to Customer zone goes through a Distribution Center.
- Eq. 5.9 enforces that the number of products sold at each Customer zone is less than the demand at that point for a specific product.
- Eq. 5.10 matches products sold at customer zones to supplied products.
- Eq. 5.11 ensures that the number of total products handled at each DC is within DC capacity.
- Eq. 5.12 and 5.13 enforces that each customer zone is serviced by only one DC.
- Eq. 5.14 and Eq. 5.15 specify the number of DCs utilized within the model.
- Eq. 5.16 calculates "Total Inventory Costs" based on the number of DCs utilized within the model.
- Eq. 5.17 calculates "Lost Sales Costs" based on disruption probabilities and the number of DCs utilized within the model.
- Eq. 5.18 calculates "Lost Sales" based on disruption probabilities and the number of DCs utilized within the model.
- Eq. 5.19 ensures that maximum one DC is utilized at each city.
- Eq. 5.20 ensures non-negativity for all variables.
- Eq. 5.21 restricts the binary variables.

5.2. Problem Definition for a Real – Life Scenario

In that section of the chapter, a real life problem along with brief information on the company is presented. Then, the summary of the company SC network data which will be used while applying the model is provided.

5.2.1. Company Profile

XYZ Group company is one of the leading Ready – Wear clothing companies primarily based in Turkey. The Company has around 150 retail stores throughout Turkey, 3 Multi-Storey Mega Stores and over 500 sales points. The firm is one of the First 500 Big Industrial Organizations of Turkey in terms of sales volume, number of employees, etc.

In their stores, the firm does not only sell products which produced at its own plant but also some other products which have been either bought from other brands or get other subcontractors produce on firm's brands.

The Group does not only operates in Turkey, but also carries the superior features of Turkish design and production to a wide geography extending from the Middle East to the Balkans, with 4 different international trademarks.

5.2.2. Problem Definition

The company currently has only one Distribution Center (DC) in Istanbul. That DC supports all sales points all over Turkey. However, the number of sales points and the total sales volume of the company increased sharply, in recent years. It is considered that the firm needs to reconfigure its supply chain network and to decide whether or not to open additional DC(s) in alternative locations; İzmir or Ankara. In case of opening a new DC, firm also need to make a decision on the capacity of the new DC.

It is also thought that DC being closer to the customer zones has a positive effect on total sales. In their retail stores, the firm has very limited storage capacity since most of them are located within big shopping centers; malls. Besides that, the number of SKU for ready – wear clothing business is enormously high because of different size and the color of each product type. Instead of keeping the right size and color of the all different products, stores demand them from either other stores or DCs. In current network configuration, the firm does not guarantee to transport the right size and color of the product within a day due to the distance between retail stores and the DC. It is assumed that the firm may guarantee to transport the requested products within a day to the stores which are not more than 600 kilometers away from Distribution Centers.

In the proposed model, it is aimed to build a multi-objective Mixed Integer Linear Programming (MILP) model to solve the company's problem. Three objectives are Profit maximization, Sales maximization, and Risk minimization. The proposed model both optimizes the current network traffic and try to capture the demand variance depending on the SC configuration decisions and its effects on the SC performances. The current configuration of the SC network, the defined problem and the sales volume data are real data gathered from the company. However, not all the required data such as price elasticity, demand variance etc. is not currently available. Wherever the real life data is not available, the hypothetical dataset is generated to be used in order to solve the model.

5.2.3. Real Life Scenario Model Details and Data Summary

The model is built as MILP with three echelon SC network, multi products, and single period as proposed in model definition.

5.2.3.1. SC network

The current SC structure of the company consists of three echelons. Figure 5-1 depicts the current network of the company:

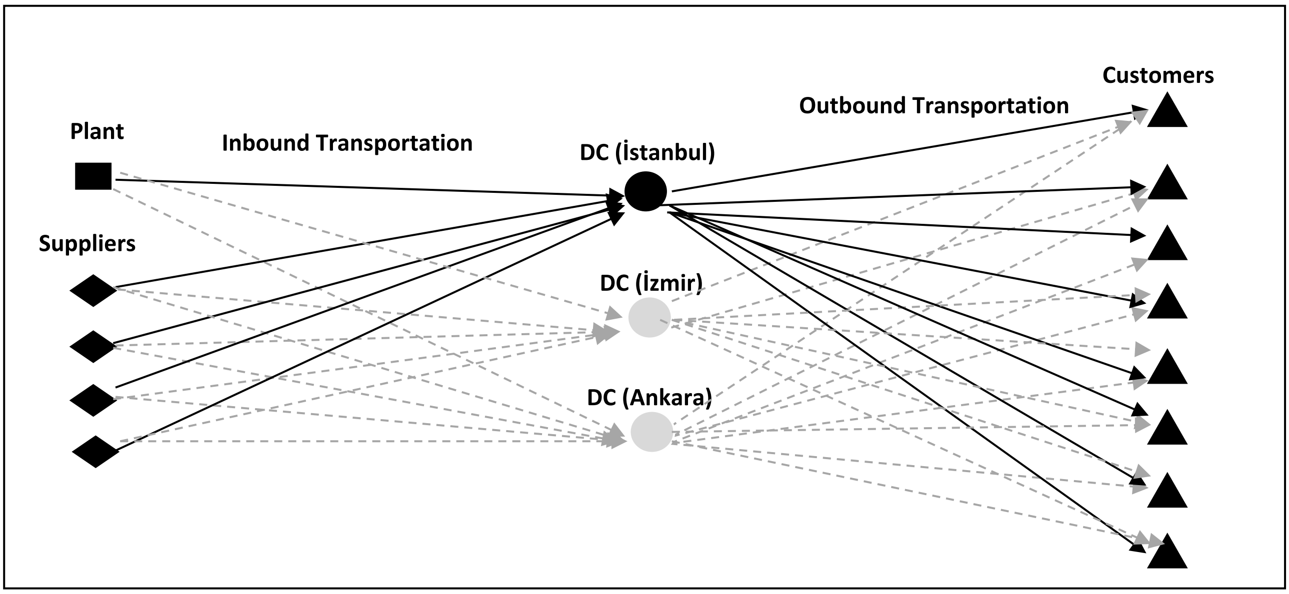

Figure 5-1. Current Supply Chain Network of XYZ Company

(4) Suppliers: The merchants are either supplied by company's own plant or external suppliers. The model defines which types of products are supplied by which suppliers by predefined rates. The defined rates are presented on Table 1 in Appendix III.

(5) Distribution Center: The Company currently has only one DC and all the products are distributed through this single DC. The Current DC is in Istanbul and there are two alternative locations to be analyzed for new DC(s). These alternatives are Ankara and Izmir. There are also three different capacity alternatives defined for potential DCs.

(6) Customer Zones: Customer zones are spread around Turkey. The company has 209 retail outlets. The demand for the retail outlets are aggregated to 39 city locations. The cities, the number of retail outlets and the aggregated demand for each city is presented on Table 2 in Appendix III.

5.2.3.2. Products data

The company has enormous number of SKU to provide to the customer zones. In order not to make the model too complicated, SKU are aggregated to 10 different product types to represent the whole product mix of the company. Product categories are presented below on Table 5.1;

Table 5-1. Product categories

Product Category Number	Product Category
1	Chino
2	Çorap
3	Denim
4	Gömlek
5	Kanvas
6	MKP
7	Örme
8	Sweat Shirt
9	Triko
10	T-shirt

The base price of each type of the product is also provided on Table 5.2.

Table 5-2. Average Base Price

Product Category Number	Product Category	Average Price – Base Price (TL)
1	Chino	18
2	Çorap	1,5
3	Denim	36
4	Gömlek	12
5	Kanvas	12
6	MKP	30
7	Örme	20
8	Sweat Shirt	15
9	Triko	15
10	T-shirt	10

5.2.3.3. One – day replenishment coverage data

In current SC network, only some of the stores are provided by the right product within one day. As explained while defining the proposed model, it is assumed that, in case, the distance between DC and retail outlet is less than 600 kilometers the right product will be provided from DC in one day. Whether the distance between DC and customer zone is over 600 kilometers, or not, is provided on Table 5 in Appendix III.

5.2.3.4. *Cost parameters data*

Unit product costs; calculated as the unit costs multiplied by sales volume of each product type. Unit costs are provided on Table 5.3.;

Table 5-3. Unit Product Costs

Product Category Number	Product Category	Cost (TL)
1	Chino	12
2	Çorap	1
3	Denim	24
4	Gömlek	8
5	Kanvas	8
6	MKP	20
7	Örme	15
8	Sweat Shirt	10
9	Triko	12
10	T-shirt	6

Transportation costs; inbound transportation costs; the costs from each supplier to the alternative DC locations for each product type are provided on Table 3 in Appendix III.

Outbound transportation costs; provided on Table 4 in Appendix III. Since the volume of the products, in outbound transportation is much smaller than the costs in inbound transportation, rates per product are much higher.

Facility costs; DC fixed costs according to the capacity of the DCs are provided on Table 5.4;

Table 5-4. DC fixed costs

DC	Fixed Costs (TL)	Capacity (item per the analyzed term)
İstanbul	1.250.000	5.000.000
Ankara	250.000	250.000
Ankara	400.000	500.000
Ankara	500.000	1.000.000
İzmir	250.000	250.000
İzmir	400.000	500.000
İzmir	500.000	1.000.000

Inventory Costs; in the current configuration and the state of the SC, inventory costs per item are calculated and provided below as the first row of Table 5.5. In the calculation, required Customer Service Level is assumed to be 99 %. Besides the current configuration, inventory costs per product for scenario with 2 DCs and with 3 DCs are calculated and provided below on Table 5.5.

Table 5-5. Per item inventory costs for each product type

Scenario	CHINO	ÇORAP	DENIM	GÖMLEK	KANVAS	MKP	ÖRME	SW.SHRT	TRIKO	TSHIRT
1 DC	0,223	0,015	0,223	0,079	0,168	0,471	0,290	0,102	0,147	0,089
2 DCs	0,277	0,020	0,228	0,089	0,228	0,707	0,370	0,127	0,180	0,099
3 DCs	0,297	0,022	0,240	0,107	0,240	0,722	0,483	0,135	0,202	0,117

Disruption Costs; as defined in the model, disruption costs are calculated as the total sales times disruption probability of the whole SC network multiplied by shortage costs. Shortage costs for each product type are presented below on Table 5.6;

Table 5-6. Shortage Costs

Product Category	Shortage Costs (TL)
Chino	6
Çorap	0.5
Denim	12
Gömlek	4
Kanvas	4
MKP	10
Örme	5
Sweat Shirt	5
Triko	3
T-shirt	4

5.3. Results of the Model

After defining the problem and formulating the mathematical model which aims to solve the problem, the model is run under various scenarios and the results for each scenario are generated. The mathematical model explained in the previous section is defined on GAMS modeler software and the Cplex solver is utilized to solve the model. The GAMS Model is also provided as Appendix IV.

In this section of the application chapter, first, single objective profit maximization, sales maximization, and risk minimization model results are provided. Then, a multi-objective optimization approach is defined to build a multi-objective model. After defining three-objective model, whose objectives are maximization of the total profit, maximization of the total sales; and the minimization of the SC disruption risk, the results for the model are generated and provided.

5.3.1. Single Objective Model

5.3.1.1. Single objective model - profit maximization

First, the problem is solved as a single objective profit maximization problem. Since the firm operates in retail ready-made clothing industry, the price elasticity coefficient is assumed to be as high as 2.5. Please find all the coefficients utilized in the model summarized below on Table 5-7;

Table 5-7. Model base scenario parameters.

α: (Price Elasticity)	β: (Coverage Elasticity)	µ: (Inbound Transportation Disruption Probability)	δ: (DC Disruption Probability)	Φ: (Outbound Transportation Disruption Probability)
-2.5	0.10	0.50%	1.00%	2.00%

Single objective profit maximization model results for the allowed price range (between % 15 price increase and % 15 price decrease) is provided below on Table 5-8;

Table 5-8.Model Results for profit maximization problem

Price Change (%)	Number of DC(s)	Risk Value	Total Revenue [TL)	Total Costs (TL)	Total Profit (TL)	Total Number of Sales
-15	1	0.965	31,375,600	30,388,160	987,445	2,554,448
-14	1	0.965	32,707,190	31,404,790	1,302,403	2,611,845
-13	1	0.965	33,447,060	31,825,770	1,621,288	2,612,254
-12	1	0.965	35,436,670	33,485,030	1,951,641	2,703,416
-11	1	0.965	35,550,400	33,277,090	2,273,307	2,678,900
-10	1	0.965	35,330,820	32,749,180	2,581,643	2,632,306
-9	1	0.965	35,336,770	32,459,430	2,877,332	2,602,784
-8	1	0.965	36,239,010	33,070,220	3,168,790	2,637,051
-7	1	0.965	36,966,750	33,511,430	3,455,319	2,658,378
-6	1	0.965	36,616,020	32,886,250	3,729,770	2,604,831
-5	1	0.965	36,249,100	32,261,070	3,988,031	2,551,284
-4	1	0.965	36,116,770	31,884,080	4,232,681	2,514,671
-3	1	0.965	35,714,340	31,253,260	4,461,076	2,460,739
-2	1	0.965	35,295,600	30,622,440	4,673,162	2,406,808
-1	1	0.965	34,860,560	29,991,620	4,868,939	2,352,876
BasePrice	1	0.965	34,409,210	29,360,800	5,048,408	2,298,944
1	1	0.965	33,941,540	28,729,980	5,211,567	2,245,013
2	1	0.965	33,457,570	28,099,160	5,358,417	2,191,081
3	1	0.965	32,957,290	27,468,330	5,488,959	2,137,149
4	1	0.965	32,440,700	26,837,510	5,603,191	2,083,218
5	1	0.965	31,907,810	26,206,690	5,701,114	2,029,286
6	1	0.965	31,358,600	25,575,870	5,782,729	1,975,354
7	1	0.965	30,793,080	24,945,050	5,848,034	1,921,423
8	1	0.965	30,211,260	24,314,230	5,897,031	1,867,491
9	1	0.965	29,613,130	23,683,410	5,929,718	1,813,560
10	1	0.965	28,998,680	23,052,590	5,946,097	1,759,628
11	1	0.965	28,367,930	22,421,760	**5,946,167***	1,705,696
12	1	0.965	27,720,870	21,790,940	5,929,927	1,651,765
13	1	0.965	27,057,500	21,160,120	5,897,379	1,597,833
14	1	0.965	26,377,820	20,529,300	5,848,522	1,543,901
15	1	0.965	25,681,840	19,898,480	5,783,355	1,489,970

Table 5-8 shows that when the price is decreased, the profit also decreases due to the decreasing profit margin. Even though increasing sales generates more revenue; however, cost increase is more than the revenue increase. More than % 7 decrease in the price, as seen on Table 5-8, even the revenue starts to decrease since the model choose not to fill all of the total demand on the market.

Below figure 5-2 shows how total profit and total number of sales changes against the changes in the price. The figure represents that when the price is increased, the profit also starts to increase due to the increasing profit margin. Even though decreasing sales generates less revenue however cost decrease is more than the revenue increase. Therefore, the total profit also increases up to % 11 price increase. After that point, the revenue decrease becomes more than cost savings. Therefore, total profit starts to decrease.

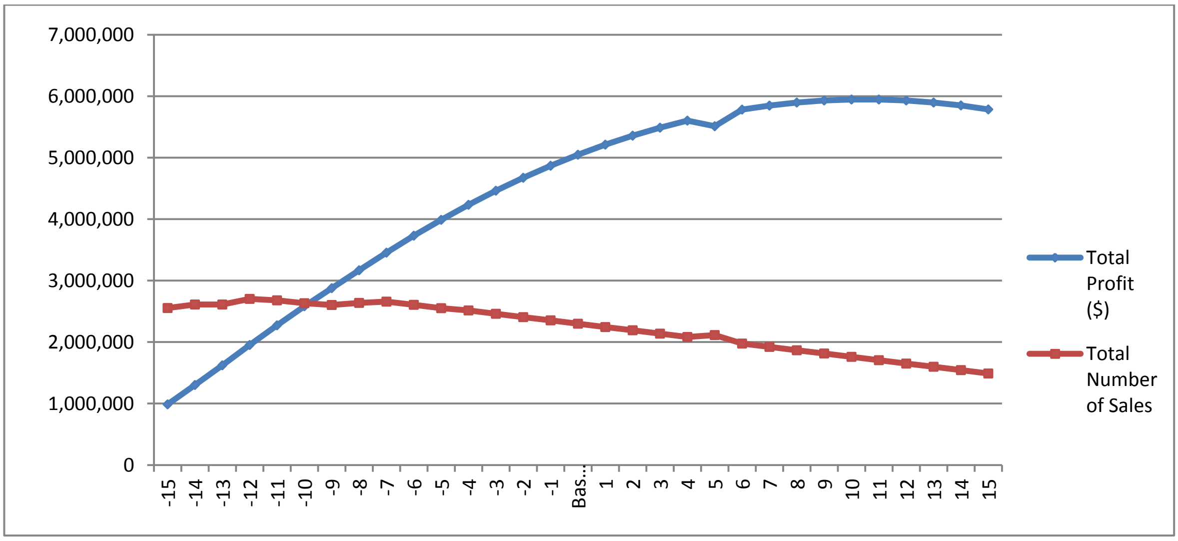

Figure 5-2. Total Profit and Total Sales Changes in Profit Maximization Problem

In the optimal solution for MIP profit maximization problem, the price is increased by % 11. At that optimal point, only one DC, the current DC is opened. Also at that point, total costs is increased by 5 % and the model does not choose to open any additional DC due to fixed cost of opening additional DC.

In the profit maximization problem, in any case, the model chooses not to open any additional DC. Because, the fixed cost of opening DC is more than the additional profit generated by opening second DC even though the sales volume is increased.

At the optimal point, even though the profit is maximized, the sales decreased by 26 %. Because of the competition within the market, the 26 % sales decrease is not acceptable by any firm since the firms aim not to lose market share in order to keep its long term profitability sustainable. Besides sales decrease, the risk value of 0.965 is also high in optimal solution. Therefore, it may be concluded that modeling the problem as profit maximization does not generate required results.

5.3.1.2. Single objective model – sales maximization

As a second alternative of single objective model, the problem is also solved as a sales maximization problem with the same coefficients. For each price change alternative, the model is optimized to determine the network configuration which maximizes the total sales volume.

Within the model, the sales are influenced by price and the number and the location of DCs. In some cases, with the same price and the number of DCs, there is more than one alternative solution. Therefore, the model is configured to determine the alternative which maximizes the sales and determines the most profitable alternative at the same sales level.

Table 5-9. Model Results for sales maximization problem

Price Change (%)	Number of DC(s)	Risk Value	Total Revenue (TL)	Total Costs (TL)	Total Profit (TL)	Total Number of Sales
-15	3	1	40,868,640	41,361,460	-492,823	3,294,016 *
-14	3	1	40,648,160	40,727,780	-79,621	3,238,149
-13	3	1	40,411,380	40,092,520	318,858	3,182,282
-12	3	1	40,158,290	39,458,870	699,413	3,126,415
-11	3	1	39,888,890	38,825,230	1,063,661	3,070,548
-10	3	1	39,603,180	38,191,580	1,411,599	3,014,681
-9	3	1	39,301,160	37,557,830	1,743,332	2,958,814
-8	3	1	38,982,830	36,924,180	2,058,650	2,902,947
-7	3	1	38,648,190	36,290,630	2,357,559	2,847,080
-6	3	1	38,297,250	35,660,160	2,637,092	2,791,213
-5	3	1	37,929,990	35,023,240	2,906,751	2,735,346
-4	3	1	37,546,440	34,391,030	3,155,402	2,679,479
-3	3	1	37,146,560	33,753,080	3,393,483	2,623,612
-2	3	1	36,730,380	33,133,890	3,596,488	2,567,745
-1	3	1	36,297,890	32,486,290	3,811,604	2,511,878
Base Price	3	1	35,849,090	31,855,020	3,994,073	2,456,011
1	3	1	35,383,980	31,217,460	4,166,524	2,400,144
2	3	1	34,902,570	30,583,900	4,318,662	2,344,277
3	3	1	34,404,840	29,950,350	4,454,490	2,288,410
4	3	1	33,890,800	29,123,630	4,767,177	2,232,543
5	3	1	33,360,460	28,488,810	4,871,652	2,176,676
6	3	1	32,813,810	27,855,110	4,958,697	2,120,809
7	3	1	32,250,840	27,216,130	5,034,715	2,064,942
8	3	1	31,671,570	26,582,570	5,088,999	2,009,075
9	3	1	31,075,990	25,949,020	5,126,974	1,953,208
10	3	1	30,464,100	25,315,460	5,148,640	1,897,341
11	3	1	29,835,910	24,681,910	5,153,997	1,841,474
12	3	1	29,191,400	24,048,350	5,143,045	1,785,607
13	3	1	28,530,580	23,414,800	5,115,784	1,729,740
14	3	1	27,853,460	22,784,690	5,068,766	1,673,873
15	3	1	27,160,020	22,147,690	5,012,335	1,618,006

Results for the allowed price range (between % 15 price increase and % 15 price decrease) is provided on Table 5-9;

As it may have already been expected that the sales is maximized when the price is decreased as much as possible and the maximum number of DCs are opened. The sales is maximized when the price is decreased, however, the model generates less profit after some point of the sales price. With 13 % or more sales price decrease, the model even generates minus profit. Changes in total number of sales and total profit is depicted on below figure 5-3

Another important result which needs to be emphasized is that when the price increased more than 11 %, both sales and profit decreases.

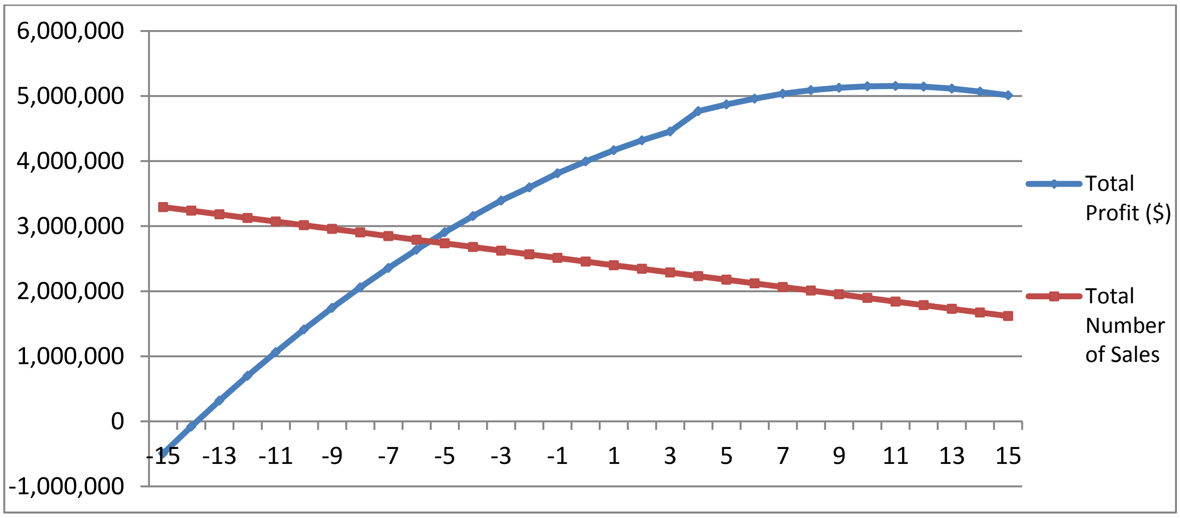

Figure 5-3. Total Profit and Total Sales Changes in Sales Maximization Problem

After reviewing the model results, it may be concluded that the sales maximization model without any consideration on the profit is not acceptable for Decision Maker (DM) since it may also generate losses which is financially unacceptable.

5.3.1.3. *Single objective model – risk value maximization*

As a third type of single objective model, the problem is solved as a risk value maximization problem. When the risk value is maximized, probability of disruption in the supply chain is also minimized. Within the model, the SC risk value is influenced only by the number of DCs opened. Therefore, there are only three alternative values for SC risk value. In order to optimize model, a secondary objective, either profit maximization or sales maximization, is utilized. Below are the results for different number of DCs and different secondary objective alternatives;

Table 5-10. Risk value maximization problem results (Profit maximization as secondary objective)

Number of DC(s)	Price Change (%)	Risk Value	Total Revenue (TL)	Total Costs (TL)	Total Profit (TL)	Total Number of Sales
1	+11	0.965	28,367,930	22,421,760	5,946,167	1,705,696
2	+11	0.999	29,121,060	23,330,780	5,790,283	1,780,236
3	+11	1.000	29,570,970	24,186,500	5,384,471	1,823,773

Table 5-11. Risk value maximization problem results (Sales maximization as secondary objective)

Number of DC(s)	Price Change (%)	Risk Value	Total Revenue (TL)	Total Costs (TL)	Total Profit (TL)	Total Number of Sales
1	-15	0.965	39,467,050	38,823,110	643,945	3,107,919
2	-15	0.999	40,777,990	40,769,630	8,351	3,285,530
3	-15	1.000	40,868,640	41,361,460	-492,823	3,294,016

5.3.1.4. *Single objective model – summary of findings*

Optimal solution summary for separate single objective problems are summarized on below figure 5-4. As summarized on the figure, in single objective model, the model generates different solutions depending on the chosen objective. For example, when the profit is maximized, the sales decreases by % 25.8. On the other hand, when the sales is maximized at the lowest price level (% 15 price decrease), the total profit decreases to - TL 492,823, which is not acceptable because of being non-profitable. On the other hand, when "risk value" is increased by opening new DCs, the profit decreases and the sales level slightly increases.

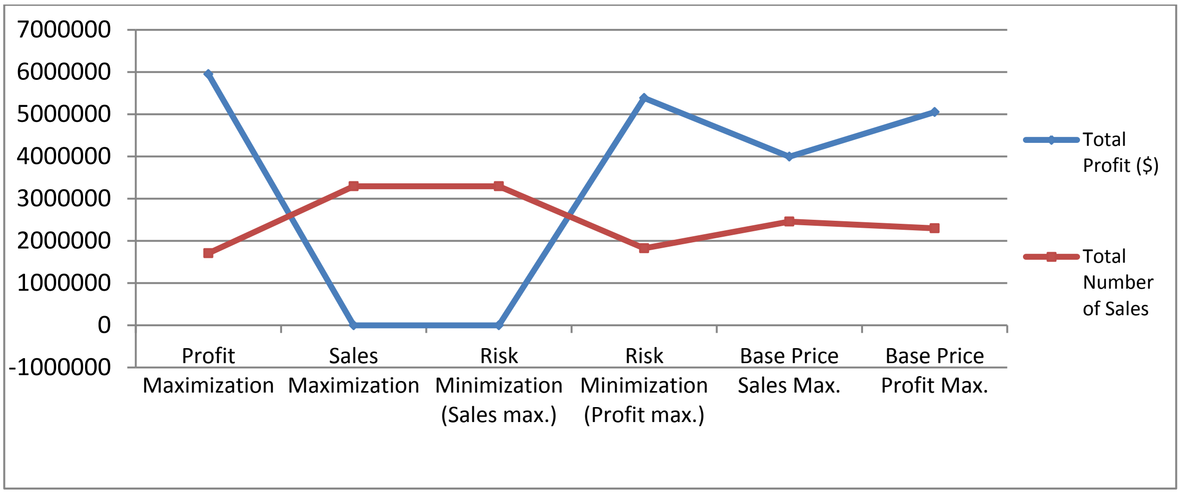

Figure 5-4. Optimal Solution Summary for Various Single Objective Models

The figure also shows that "sales volume" and "total profit" are changing adversely, that is, when the sales volume increases, total profit decreases. The balance between those two objectives is totally dependent on the difference between marginal revenue generated by the increasing sales and the additional cost (especially cost of opening an additional DC).

Below table 5-12 depicts how the model objectives are influenced by the decision variables utilized within the model. According to the table, only two major decision variables have major impacts on the value of model objectives regardless of the chosen objective.

Table 5-12. Impacts of Decision Variables on Model Objectives

	Model Objectives		
Decision Variables	Total Profit	Total Sales	Risk Value
Number and Location of DCs	Major	Major	Major
Sales Price	Major	Major	x
Capacity of DCs	Minor	x	x
Network Traffic	Minor	x	x
DC-Customer Zone Allocation	Minor	x	x
Fill Rate	Minor	Minor	x

In conclusion, as emphasized after the literature review section, it is not possible to make a SC network configuration decision only by single objective. A method incorporating all three objectives, profit maximization, sales maximization, and risk minimization needs to be applied to find the optimal solution to the problem.

5.3.2. Multi Objective Model

5.3.2.1. Multi-objective optimization approach utilized within the model

As detailed on literature review section, there are several approaches utilized to handle with the multi-objective SC network optimization models within the literature. Multi-objective solution approaches such as weighted objective or goal programming are generally criticized on being dependent on the subjective importance of the each objective. Therefore, as seen on the multi-objective model review, in some cases, instead of providing one single mathematically optimal solution, the modelers try to shorten the list of alternative optimal solutions by scenario analysis where the alternative number of scenarios is limited.

As seen on single objective solutions provided in single objective model section and summarized on table 5-12, the results on each objective are substantially dependent on the strategic level SC decisions such as the number and the locations of the DCs, and the price change level. Besides strategic level decisions, tactical level decisions, that is, SC network traffic decisions and the demand fill rate decisions have no influence on SC Risk Value and minor influence on SC Profit and Total Sales Volume.

Another important conclusion drawn from single objective model result is that after 11 % price increase, both profit and the sales level decreases regardless of the number of DCs. Therefore, the price range which needs to be explored should be between 15 % price decrease and 11 % price increase.

In our model, the major determinants are the number of DCs and the price change alternatives. Also, the alternative scenarios for those determinants are limited. Therefore, it would be a good idea to optimize the model for each alternative scenario (price change and number of DC combination) and provide solutions to decision makers. However, there is still a need to convert profit maximization and sales maximization objectives into one single objective for each scenario (price change and number of DC combination) solutions. In order to convert those two objectives into one single objective goal programming methodology is utilized.

In goal programming method, first the goals for each objective need to be determined. The goals are defined as 10 % increase from the current level of the objectives (at base scenario) and then the objectives are rescaled. Then a distance functions from each objective (d_1 and d_2) are defined. The goal function is set to minimize the total distance from both goals.

Since the multi-objective approach utilized in this study combines scenario analysis and goal programming method it may be called as a hybrid methodology.

5.3.2.2. Multi-objective optimization model – results

In multi objective model, the same coefficients of parameters are utilized. Please find all the coefficients utilized in the model solution summarized below on Table 5-13;

Table 5-13. Model parameters – Multi-objective problems

α: (Price Elasticity)	β: (Coverage Elasticity)	μ: (Inbound Transportation Disruption Probability)	δ: (DC Disruption Probability)	Φ: (Outbound Transportation Disruption Probability)
-2.5	**0.10**	**0.50%**	**1.00%**	**2.00%**

The goals for the model are defined as 10 % increase from current level. Those goals are;

Target Profit : TL 5.550.000

Target Sales: 2.530.000 items

Distance Functions:

Profit Distance (d_1): Total Profit – Target Profit

Sales Distance (d_2): Total Sales – Target Sales

Objective Function:

$$\text{Maximization of Total Distance} = d_1 + 2*d_2$$

In Distance Function Formula, sales volume is multiplied by two in order to rescale objectives to be at the same level since the profit are about two times more than the sales volume in base scenario at base price level. Other than rescaling, relative weights of the two separate objectives are assumed to be same.

The model is defined and run on GAMS Modeler. Cplex solver is utilized to solve the model. The basic statistics about the model is provided below;

MODEL STATISTICS

BLOCKS OF EQUATIONS	35	SINGLE EQUATIONS	4,761
BLOCKS OF VARIABLES	24	SINGLE VARIABLES	6,446
NON ZERO ELEMENTS	30,283	DISCRETE VARIABLES	282

Results for the pre-determined price range (between % 11 price increase and % 15 price decrease) is provided below on Table 5-14;

As seen on the table, multi objective model results quite differ from single objective model results. As it may have been remembered that the sales is maximized when three DCs are opened and the price is decreased as much as allowed. On the other hand, the profit is maximized when the price is increased at % 11 and only one DC (current one) is utilized within SC.

However, in the multi-objective model, the distance function is maximized when the price is increased by % 4 and two DCs are utilized concurrently. Full details of the results at that point with traffic network decisions are provided as Appendix V.

Table 5-14.Results for Multi-objective Model (Maximizing Distance Function)

Price Change (%)	Number of DC(s)	Risk Value	Total Revenue (TL)	Total Costs (TL)	Total Profit (TL)	Total Number of Sales	Distance Function
-15	1	0.965	39,467,060	38,823,120	643,943	3,107,919	-3,750,220
-15	2	0.999	40,138,040	39,604,990	533,053	3,233,980	-3,608,980
-15	3	1.000	40,353,800	40,341,350	12,452	3,252,453	-4,092,640
-14	1	0.965	39,244,030	38,192,300	1,051,737	3,053,988	-3,450,290
-14	2	0.999	39,909,180	38,972,520	936,655	3,178,142	-3,317,060
-14	3	1.000	40,116,090	39,693,090	423,001	3,195,564	-3,795,870
-13	1	0.965	39,004,700	37,561,480	1,443,222	3,000,056	-3,166,660
-13	2	0.999	39,655,430	38,328,450	1,326,977	3,121,482	-3,040,060
-13	3	1.000	39,836,630	39,020,020	816,610	3,136,883	-3,519,620
-12	1	0.965	38,749,050	36,930,650	1,818,398	2,946,124	-2,899,350
-12	2	0.999	39,397,600	37,698,440	1,699,156	3,065,941	-2,778,960
-12	3	1.000	39,616,150	38,424,680	1,191,470	3,084,036	-3,250,460
-11	1	0.965	38,477,100	36,299,830	2,177,264	2,892,193	-2,648,350
-11	2	0.999	39,109,530	37,055,390	2,054,143	3,009,489	-2,536,880
-11	3	1.000	39,359,920	37,812,210	1,547,710	3,029,617	-3,003,050
-10	1	0.965	38,188,830	35,669,010	2,519,822	2,838,261	-2,413,650
-10	2	0.999	38,825,600	36,433,580	2,392,013	2,954,265	-2,309,460
-10	3	1.000	39,076,400	37,189,970	1,886,436	2,974,464	-2,774,630
-9	1	0.965	37,884,260	35,038,190	2,846,071	2,784,329	-2,195,270
-9	2	0.999	38,556,290	35,847,990	2,708,306	2,901,529	-2,098,630
-9	3	1.000	38,811,340	36,599,100	2,212,245	2,921,739	-2,554,280
-8	1	0.965	37,563,380	34,407,370	3,156,011	2,730,398	-1,993,190
-8	2	0.999	38,232,810	35,214,950	3,017,860	2,845,920	-1,900,300
-8	3	1.000	38,492,610	35,968,510	2,524,097	2,866,270	-2,353,360
-7	1	0.965	37,226,190	33,776,550	3,449,642	2,676,466	-1,807,420
-7	2	0.999	37,890,210	34,580,670	3,309,545	2,790,082	-1,720,290
-7	3	1.000	38,156,600	35,338,020	2,818,576	2,810,700	-2,170,020
-6	1	0.965	36,872,690	33,145,730	3,726,964	2,622,534	-1,637,970
-6	2	0.999	37,539,220	33,956,900	3,582,321	2,734,785	-1,558,110
-6	3	1.000	37,818,860	34,721,280	3,097,577	2,754,131	-2,004,160
-5	1	0.965	36,502,880	32,514,910	3,987,977	2,568,603	-1,484,820
-5	2	0.999	37,175,330	33,330,390	3,844,937	2,679,040	-1,406,980
-5	3	1.000	37,463,800	34,098,810	3,364,982	2,700,056	-1,844,900
-4	1	0.965	36,116,770	31,884,080	4,232,681	2,514,671	-1,347,980
-4	2	0.999	36,789,290	32,701,480	4,087,804	2,624,330	-1,273,530
-4	3	1.000	37,086,220	33,474,380	3,611,837	2,644,667	-1,708,830
-3	1	0.965	35,714,340	31,253,260	4,461,076	2,460,739	-1,227,440
-3	2	0.999	36,381,710	32,067,430	4,314,285	2,568,492	-1,158,730
-3	3	1.000	36,688,100	32,844,330	3,843,770	2,589,170	-1,587,890
-2	1	0.965	35,295,600	30,622,440	4,673,162	2,406,808	-1,123,220
-2	2	0.999	35,957,830	31,434,960	4,522,868	2,512,653	-1,061,820
-2	3	1.000	36,270,290	32,213,980	4,056,300	2,535,405	-1,482,890
-1	1	0.965	34,860,560	29,991,620	4,868,939	2,352,876	-1,035,310
-1	2	0.999	35,517,630	30,802,490	4,715,142	2,456,815	-981,226
-1	3	1.000	35,843,920	31,590,830	4,253,096	2,479,740	-1,397,420
Base Price	1	0.965	34,409,210	29,360,800	5,048,408	2,298,944	-963,701
Base Price	2	0.999	35,087,180	30,195,250	4,891,933	2,402,777	-912,511
Base Price	3	1.000	35,391,470	30,955,090	4,436,379	2,424,493	-1,324,630
1	1	0.965	33,941,540	28,729,980	5,211,567	2,245,013	-908,405
1	2	0.999	34,614,630	29,562,850	5,051,779	2,346,939	-864,341
1	3	1.000	34,935,940	30,333,360	4,602,583	2,369,480	-1,268,460
2	1	0.965	33,457,570	28,099,160	5,358,417	2,191,081	-869,418
2	2	0.999	34,143,180	28,945,540	5,197,643	2,292,318	-827,719
2	3	1.000	34,493,100	29,746,250	4,746,853	2,316,663	-1,229,820
3	1	0.965	32,957,290	27,468,330	5,488,959	2,137,149	-846,740
3	2	0.999	33,646,870	28,318,170	5,328,699	2,237,044	-807,211
3	3	1.000	34,016,160	29,129,950	4,886,214	2,260,108	-1,203,570

Price Change (%)	**Number of DC(s)**	**Risk Value**	**Total Revenue (TL)**	**Total Costs (TL)**	**Total Profit (TL)**	**Total Number of Sales**	**Distance Function**
4	1	0.965	32,440,700	26,837,510	5,603,191	2,083,218	-840,371
4	2	0.999	33,135,610	27,694,040	5,441,572	2,181,838	-804,750
4	3	1.000	33,517,810	28,510,660	5,007,150	2,206,310	-1,190,230
5	1	0.965	31,907,810	26,206,690	5,701,114	2,029,286	-850,311
5	2	0.999	32,605,040	27,065,240	5,539,796	2,126,486	-817,230
5	3	1.000	32,986,690	27,878,550	5,108,134	2,152,230	-1,197,400
6	1	0.965	31,358,600	25,575,870	5,782,729	1,975,354	-876,560
6	2	0.999	32,064,140	26,442,230	5,621,910	2,070,200	-847,688
6	3	1.000	32,453,890	27,260,160	5,193,736	2,097,463	-1,221,340
7	1	0.965	30,793,080	24,945,050	5,848,034	1,921,423	-919,118
7	2	0.999	31,505,410	25,818,390	5,687,015	2,015,344	-892,295
7	3	1.000	31,898,190	26,634,310	5,263,874	2,042,278	-1,261,570
8	1	0.965	30,211,260	24,314,230	5,897,031	1,867,491	-977,985
8	2	0.999	30,931,300	25,195,520	5,735,773	1,961,138	-951,950
8	3	1.000	31,369,950	26,054,790	5,315,156	1,989,348	-1,316,150
9	1	0.965	29,613,130	23,683,410	5,929,718	1,813,560	-1,053,160
9	2	0.999	30,340,230	24,570,720	5,769,508	1,906,141	-1,028,210
9	3	1.000	30,782,560	25,428,450	5,354,102	1,934,778	-1,386,340
10	1	0.965	28,998,680	23,052,590	5,946,097	1,759,628	-1,144,650
10	2	0.999	29,736,490	23,948,860	5,787,622	1,850,741	-1,120,890
10	3	1.000	30,185,970	24,809,240	5,376,731	1,878,594	-1,476,080
11	1	0.965	28,367,930	22,421,760	5,946,167	1,705,696	-1,252,440
11	2	0.999	29,113,800	23,325,370	5,788,433	1,796,138	-1,229,290
11	3	1.000	29,570,970	24,186,500	5,384,471	1,823,773	-1,577,980

At the optimal point of the multi-objective model, as seen on Appendix V, two DCs are concurrently opened; current DC and a new DC at Ankara. Ankara DC is proposed by model to be opened with the least possible capacity. Compared to current situation with one DC, opening second DC in Ankara helps SC network increase its sales around 5 % mainly due to one day replenishment coverage effect. However, the profit is decreased around % 3.1. At the optimal point, only 7 out of 39 customer locations are replenished by the new DC.

Compared to the optimal point of profit maximization problem (1 DC, 11 % price increase), the profit is decreased by only around % 8.5, however, the sales volume is increased by around 28 %. On the other hand, as opposed to optimal point of sales maximization problem, the profit is increased by 6 Million TL, however, the sales volume is decreased by % 33.8.

As opposed to single objective models, when the multi-objective model tries only to maximize the distance function regardless of the price and number of DC scenarios, the result generated by the model seems quite balanced in terms of total sales volume, total profit and the risk value. At the optimal point, even though the distance function is maximized, the sales volume of the company decreases due to the increasing sales price.

In most cases, the firms (DMs) may need to see the results of the all alternative scenario results and review how the SC performance metrics change through scenarios before reaching a final decision. Therefore, it has been decided to provide all optimum solutions for various scenarios to DMs.

5.3.3. Model Run Results – Summary of Findings

As mentioned above, instead of building a model to generate a mathematically optimal solution by subjectively weighted by decision maker, optimal solution for each alternative scenario (price – number of DCs combinations) is provided above on table 5- 14. Figure 5-5, Figure 5-6 and Figure 5-7 depict how total profit, total number of sales and distance function changes through different price and number of DC combinations. By analyzing the results and the figure, some conclusions may be drawn in order to both narrow down the alternative solutions and deeply understand them.

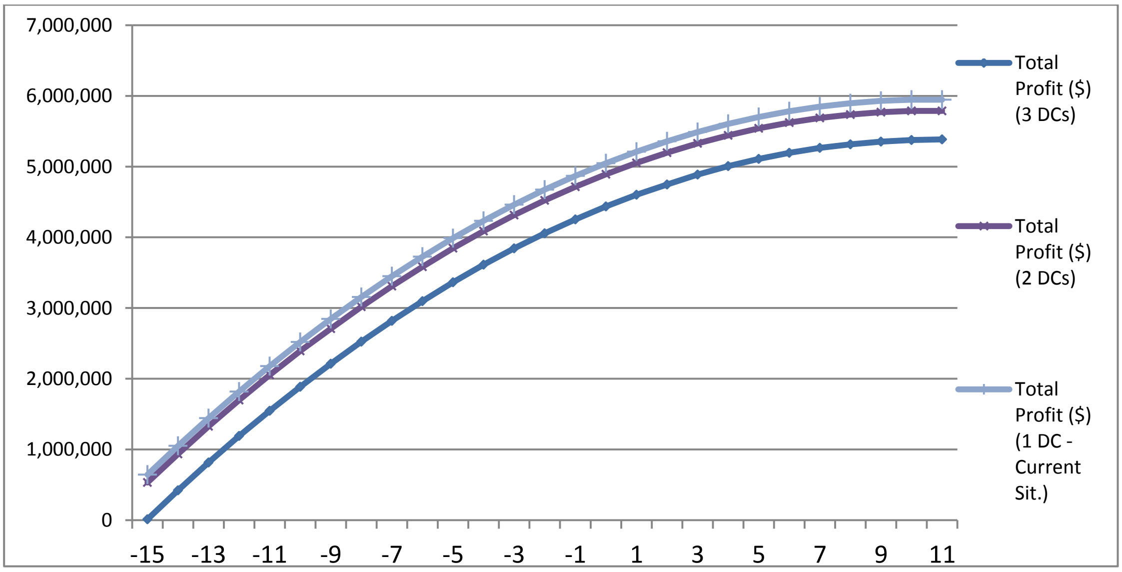

Figure 5-5. Multi-objective Solution Results through Scenarios (Total Profit)

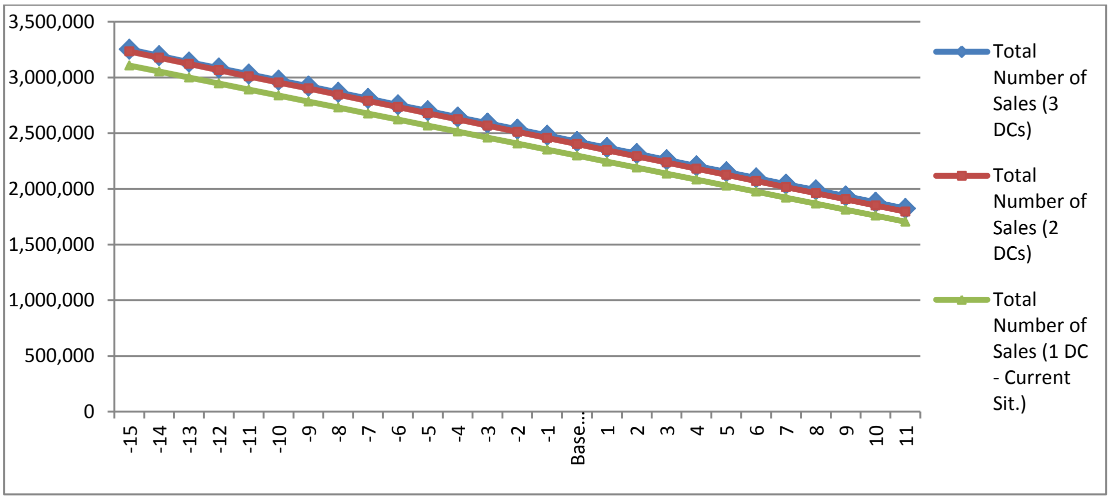

Figure 5-6. Multi-objective Solution Results through Scenarios (Total Number of Sales)

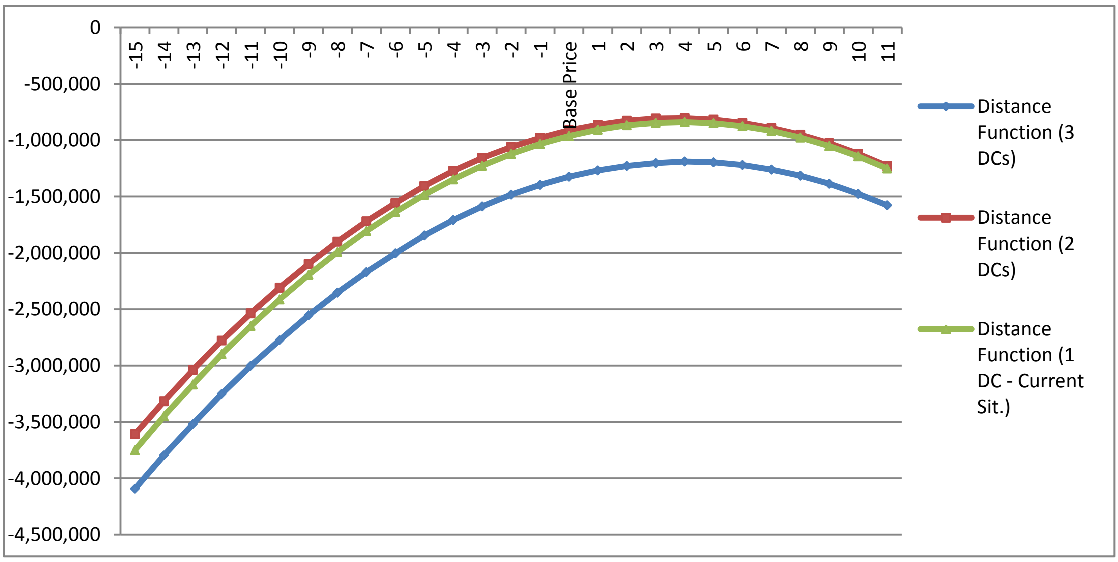

Figure 5-7. Multi-objective Solution Results through Scenarios (Distance Function)

Number of DCs: On of the most important conclusion which may be drawn from the results provided in this section is regarding the number of DCs. In any price level, when the number of DCs is increased from 2 to 3, very little impact happens on risk value (from 0.999 to 1) and on total sales (total sales is increased by around 1 %). However, total profit and eventually total distance value substantially decreases. Therefore, it may be concluded that alternatives with 3 DCs may be dropped from the alternative solutions since it has substantial negative effect on total profit and the total distance function.

On the other hand, when the model proposes to open an additional DC (from one DC to two DCs), it generally generates less profit due to increasing fixed DC costs, slightly increasing inventory holding costs, and slightly increasing transportation costs. However, alternative with two DCs, the model generates around 5 % more sales volume due to one-day replenishment coverage effect and decreasing lost sales. That also generates more revenue; however, the revenue increase is not enough to cover cost increases. Therefore, in profit maximization problems, current situation with one DC options are chosen. In a model, capturing both sales volume and profit, alternatives with two DCs are proposed to be opened since sales volume increase is more than profit decrease.

Price Decreases: Price decreases have substantial positive impact on total sales volume due to price elasticity level. However, beyond 11 % price increase, it has negative effect on the profit. The negative effect on the profit increases as the price decreases more. After 12 % price decrease the model, depending on the objective, the model may generate even negative profits. After that point the model may choose not to fill the demand at some locations because of the shrinking profit margin. Therefore, we may conclude that price decrease level beyond some point; for example, % 11 may not be reasonable and may be dropped from our final result table including all solutions for price and number of DCs combinations.

In conclusion, developed model is capable of capturing how total sales volume and total profit of the model company changes as the strategic level network configuration decisions change. The model is also capable of capturing how the SC network traffic needs to be modeled to maximize profit or sales volume or both SC objectives depending on the chosen model objectives.

The model is also utilized to model SC disruption risks. However, due to the multi-objective nature of the SC network, the model firm wants to maximize its profit, sales volume and SC risk value. In order to support decision making, the model is solved as a goal programming function. Distance maximization function of the model gives hints about the best solution for the firm’s problem. However, the objectives in the distance function are rescaled and weighted by subjective weights, providing a list of optimal solution for each scenario will help DMs.

After providing the optimal solution list for separate scenarios, sensitivity of the model needs to be analyzed in order to test whether the model generates similar results when some of the assumptions and coefficients within the model are changed.

5.4. Sensitivity Analysis

In that chapter, sensitivity of the model is analyzed in order to test the applicability of the model with respect to different parameter coefficients. These coefficients are;

- Price elasticity
- One – day replenishment coverage impact
- Risk factors – disruption probabilities
- Relative weights of the objectives.

5.4.1. Price Elasticity Coefficient (α)

First, the coefficients which have substantial effect on the demand will be analyzed to figure out how the model objectives change with respect to those coefficients. Those coefficients are price elasticity and one-day replenishment coverage area impact coefficient.

As already explained in the previous section of application chapter, price elasticity coefficient is assumed to be 2.5 since the firm operates in retail ready-made clothing industry. However, these value does not depend on a detailed market analysis or a historical sales analysis, because, there is not such a dataset or analysis currently available.

Therefore, it would be required to analyze how the model reacts on the changes on the price elasticity coefficients. Table 5-15 represents the change of the model objectives with respect to the different values of price elasticity coefficients (-1, -2, -2.5, -3, -4) respectively.

Table 5-15. Model results for different value of price elasticity coefficients (α)

Price Chng(%)	# of DC(s)	α value	Risk Value	Total Profit (TL)	Total Sales	Distance Function	α value	Total Profit (TL)	Total Sales	Distance Function	α value	Total Profit (TL)	Total Sales	Distance Function	α value	Total Profit (TL)	Total Sales	Distance Function	α value	Total Profit (TL)	Total Sales	Distance Function
-11	1	-1	0.965	1,605,571	2,536,244	-3.931.940	-2	1,986,700	2,773,543	-3,076,210	-2.5	2,177,264	2,892,193	-2,648,350	-3	2,367,829	3,010,842	-2,220,480	-4	2,748,958	3,248,142	-1,364,760
-11	2	-1	0.999	1,442,516	**2,645,308**	-3,876,870	-2	1,845,670	**2,889,660**	-2,985,010	-2.5	2,054,143	**3,009,489**	-2,536,880	-3	2,254,914	**3,132,947**	-2,089,190	-4	2,664,679	**3,378,635**	-1,188,050
-10	1	-1	0.965	1,951,174	2,514,671	-3,629,480	-2	2,330,273	2,730,398	-2,818,930	-2.5	2,519,822	2,838,261	-2,413,650	-3	2,709,372	2,946,124	-2,008,380	-4	3,088,470	3,161,851	-1,197,830
-10	2	-1	0.999	1,788,104	2,624,330	-3,573,230	-2	2,186,573	2,845,920	-2,731,590	-2.5	2,392,013	2,954,265	-2,309,460	-3	2,594,713	3,065,941	-1,883,400	-4	2,995,858	3,289,819	-1.034,503
-9	1	-1	0.965	2,290,254	2,493,098	-3,259,750	-2	2,660,799	2,687,252	-2,574,700	-2.5	2,846,071	2,784,329	-2,195,270	-3	3,031,344	2,881,406	-1,815,840	-4	3,401,889	3,075,560	-1,056,990
-9	2	-1	0.999	2,129,260	2,599,542	-3,281,650	-2	2,516,444	2,801,249	-2,491,060	-2.5	2,708,306	2,901,529	-2,098,630	-3	2,911,086	2,998,936	-1,701,040	-4	3,301,160	3,200,477	-907,883
-8	1	-1	0.965	2,622,809	2,471,526	-3,044,140	-2	2,978,277	2,644,107	-2,343,510	-2.5	3,156,011	2,730,398	-1,993,190	-3	3,333,745	2,816,688	-1,642,880	-4	3,689,213	2,989,270	-942,246
-8	2	-1	0.999	2,462,124	2,579,327	-2,989,220	-2	2,828,816	2,757,120	-2,266,940	-2.5	3,017,860	2,845,920	-1,900,300	-3	3,207,888	2,931,930	-1,538,250	-4	3,580,569	3,110,612	-808,205
-7	1	-1	0.965	2,948,842	2,449,953	-2,761,250	-2	3,282,709	2,600,962	-2,125,370	-2.5	3,449,642	2,676,466	-1,807,420	-3	3,616,575	2,751,970	-1,489,480	-4	3,950,442	2,902,979	-853,598
-7	2	-1	0.999	2,788,614	2,557,324	-2,706,740	-2	3,132,774	2,712,850	-2,051,520	-2.5	3,309,545	2,790,082	-1,720,290	-3	3,483,769	2,868,255	-1,389,720	-4	3,837,398	3,021,271	-730,059
-6	1	-1	0.965	3,268,351	2,428,380	-2,484,890	-2	3,574,093	2,557,816	-1,920,270	-2.5	3,726,964	2,622,534	-1,637,970	-3	3,879,835	2,687,252	-1,355,660	-4	4,185,577	2,816,688	-791,044
-6	2	-1	0.999	3,108,541	2,534,989	-2,431,480	-2	3,426,919	2,668,703	-1,845,670	-2.5	3,582,321	2,734,785	-1,558,110	-3	3,741,157	2,801,534	-1,265,770	-4	4,064,303	2,931,930	-681,835
-5	1	-1	0.965	3,581,336	2,406,808	-2,215,050	-2	3,852,430	2,514,671	-1,728,230	-2.5	3,987,977	2,568,603	-1,484,820	-3	4,123,524	2,622,534	-1,241,410	-4	4,394,618	2,730,398	-754,584
-5	2	-1	0.999	3,421,944	2,512,653	-2,162,750	-2	3,704,521	2,624,330	-1,656,820	-2.5	3,844,937	2,679,040	-1,406,980	-3	3,981,740	2,734,785	-1,158,690	-4	4,264,792	2,845,920	**-653,366**
-4	1	-1	0.965	3,887,797	2,385,235	-1,951,730	-2	4,117,720	2,471,526	-1,549,230	-2.5	4,232,681	2,514,671	-1,347,980	-3	4,347,642	2,557,816	-1,146,720	-4	4,577,565	2,644,107	-744,219
-4	2	-1	0.999	3,728,824	2,490,318	-1,900,540	-2	3,969,137	2,579,327	-1,482,210	-2.5	4,087,804	2,624,330	-1,273,530	-3	4,206,447	2,668,703	-1,066,140	-4	4,441,918	2,756,579	-654,923
-3	1	-1	0.965	4,187,735	2,363,662	-1,694,940	-2	4,369,963	2,428,380	-1,383,280	-2.5	4,461,076	2,460,739	-1,227,440	-3	4,552,190	2,493,098	-1,071,610	-4	4,734,417	2,557,816	-759,948
-3	2	-1	0.999	4,029,180	2,467,983	-1,644,850	-2	4,219,250	2,534,989	-1,320,770	-2.5	4,314,285	2,568,492	-1,158,730	-3	4,407,744	2,601,994	-998,265	-4	4,596,212	2,668,703	-676,380
-2	1	-1	0.965	4,481,150	2,342,090	-1,444,670	-2	4,609,158	2,385,235	-1,230,370	-2.5	4,673,162	2,406,808	-1,123,220	-3	4,737,167	2,428,380	-1.016,071	-4	4,865,175	2,471,526	-801,772
-2	2	-1	0.999	4,321,530	2,445,648	-1,397,170	-2	4,456,249	2,490,318	-1,173,110	-2.5	4,522,868	2,512,653	-1,061,820	-3	4,589,486	2,534,989	-950,535	-4	4,722,646	2,579,327	-728,698
-1	1	-1	0.965	4,768,040	2,320,517	-1,200,920	-2	4,835,306	2,342,090	-1,090,510	-2.5	4,868,939	2,352,876	-1,035,310	-3	4,902,572	2,363,662	-980,101	-4	4,969,838	2,385,235	-869,689
-1	2	-1	0.999	4,608,852	2,423,312	-1,154,520	-2	4,678,719	2,445,648	-1,039,980	-2.5	4,715,142	2,456,815	-981,226	-3	4,748,586	2,467,983	-925,446	-4	4,819,962	2,490,318	-809,400
0	1	-1	0.965	5,048,408	2,298,944	-963,701	-2	5,048,408	2,298,944	-963,701	-2.5	5,048,408	2,298,944	-963,701	-3	5,048,408	2,298,944	-963,701	-4	5,048,408	2,298,944	-1.013,701
0	2	-1	0.999	4,891,933	2,402,777	-912,511	-2	4,891,933	2,402,777	-912,511	-2.5	4,891,933	2,402,777	-912,511	-3	4,891,933	2,402,777	-962,511	-4	4,891,933	2,402,777	-962,511
1	1	-1	0.965	5,322,251	2,277,372	-733,003	-2	5,248,462	2,255,799	-849,938	-2.5	5,211,567	2,245,013	-908,405	-3	5,174,672	2,234,226	-966,873	-4	5,100,883	2,212,654	-1,083,810
1	2	-1	0.999	5,161,123	2,380,750	-687,374	-2	5,086,364	2,358,362	-806,910	-2.5	5,051,779	2,346,939	-864,341	-3	5,117,982	2,269,982	-952,051	-4	4,940,248	2,314,427	-1.040,896
2	1	-1	0.965	5,589,571	2,255,799	-508,828	-2	5,435,469	2,212,654	-749,222	-2.5	5,358,417	2,191,081	-869,418	-3	5,281,366	2,169,508	-989,615	-4	5,127,263	2,126,363	-1,230,010
2	2	-1	0.999	5,431,370	2,357,285	-464,057	-2	5,275,010	2,313,436	-708,116	-2.5	5,197,643	2,292,318	-827,719	-3	5,119,096	2,270,093	**-950,716**	-4	4,963,328	2,224,701	-1,197,270
3	1	-1	0.965	5,850,368	2,234,226	-291,177	-2	5,609,428	2,169,508	-661,553	-2.5	5,488,959	2,137,149	-846,740	-3	5,368,489	2,104,790	-1.031,928	-4	**5,127,549**	2,040,072	-1,402,300
3	2	-1	0.999	5,697,590	2,336,465	-239,478	-2	5,450,450	2,270,225	-619,098	-2.5	5,328,699	2,237,044	-807,211	-3	5,205,906	2,203,838	-996,416	-4	4,960,134	2,137,654	-1,374,560
4	1	-1	0.965	6,104,641	2,212,654	-80,050	-2	5,770,341	2,126,363	-586,931	-2.5	5,603,191	2,083,218	-840,371	-3	5,436,041	2,040,072	-1,093,810	-4	5,101,741	1,953,782	-1,600,690
4	2	-1	0.999	5,952,891	2,314,119	-28,869	-2	5,613,543	2,224,701	-497,052	-2.5	5,441,562	2,181,503	**-805,430**	-3	5,272,335	2,137,654	-1,062,360	-4	4,931,055	2,049,303	-1,580,340
5	1	-1	0.965	6,352,390	2,191,081	124,553	-2	5,918,206	2,083,218	-525,356	-2.5	5,701,114	2,029,286	-850,311	-3	5,484,022	1,975,354	-1,175,270	-4	5,049,839	1,867,491	-1,825,180
5	2	-1	0.999	6,199,167	2,291,101	171,370	-2	5,760,168	2,181,503	-436,824	-2.5	5,539,796	2,126,486	-817,230	-3	5,318,146	2,071,341	-1,149,170	-4	4,872,448	1,959,962	-1,817,630
6	1	-1	0.965	6,593,616	2,169,508	322,634	-2	6,053,024	2,040,072	-476,829	-2.5	5,782,729	1,975,354	-876,560	-3	**5,512,433**	1,910,637	-1,276,290	-4	4,971,842	1,781,201	-2,075,760
6	2	-1	0.999	6,444,577	2,269,844	374,265	-2	5,896,736	2,137,654	-387,954	-2.5	5,621,910	2,070,200	-847,688	-3	5,344,171	2,004,633	-1,256,560	-4	4,797,920	1,870,130	-2,071,820
7	1	-1	0.965	6,828,318	2,147,936	514,191	-2	6,174,795	1,996,927	-441,348	-2.5	5,848,034	1,921,423	-919,118	-3	5,521,273	1,845,919	-1,396,890	-4	4,867,751	1,694,910	-2,352,430
7	2	-1	0.999	6,679,642	2,247,647	564,937	-2	6,016,930	2,092,983	-357,101	-2.5	5,687,015	2,015,344	-892,295	-3	5,353,363	1,938,959	-1,378,720	-4	4,691,137	1,784,971	-2,348,920
8	1	-1	0.965	7,056,497	2,126,363	699,224	-2	6,283,519	1,953,782	-418,915	-2.5	5,897,031	1,867,491	-977,985	-3	5,510,542	1,781,201	-1,537,060	-4	4,737,565	1,608,619	-2,655,200
8	2	-1	0.999	6,912,803	2,225,995	754,793	-2	6,128,238	2,049,303	-333,153	-2.5	5,735,773	1,961,138	-951,950	-3	5,345,094	1,870,130	-1,524,640	-4	4,563,041	1,692,257	-2,662,440
9	1	-1	0.965	7,278,151	2,104,790	877,733	-2	6,379,196	1,910,637	-409,529	-2.5	5,929,718	1,813,560	-1,053,160	-3	5,480,241	1,716,483	-1,696,790	-4	4,581,285	1,522,329	-2,984,060
9	2	-1	0.999	7,137,110	2,203,838	934,788	-2	6,225,153	2,005,315	**-324,214**	-2.5	5,769,508	1,906,141	-1,028,210	-3	5,312,392	1,806,623	-1,684,360	-4	4,406,717	1,609,774	-2,983,730
10	1	-1	0.965	7,493,283	2,083,218	1,049,719	-2	6,461,826	1,867,491	-413,190	-2.5	5,946,097	1,759,628	-1,144,650	-3	5,430,368	1,651,765	-1,876,100	-4	4,398,911	1,436,038	-3,339,010
10	2	-1	0.999	7,353,196	2,181,503	1,106,203	-2	6,308,656	1,961,138	-329,067	-2.5	5,787,622	1,850,741	-1,120,890	-3	5,258,860	1,739,617	-1,871,900	-4	4,221,429	1,521,116	-3,346,340
11	1	-1	0.965	**7,701,891**	2,061,645	1,215,182	-2	**6,531,408**	1,824,346	-429,898	-2.5	**5,946,167**	1,705,696	-1,252,440	-3	5,360,925	1,587,047	-2,074,980	-4	4,190,442	1,349,747	-3,720,060
11	2	-1	0.999	7,562,758	2,159,168	**1,271,094**	-2	6,380,547	1,916,636	-346,179	-2.5	5,788,433	1,796,138	-1,229,290	-3	5,198,887	1,674,337	-2,062,440	-4	4,022,004	1,435,291	-3,717,410

As already explained in the conclusion part of the previous section, it would be reasonable to provide results only for price range between 11 % price decrease and 11 % price increase and the results only for one DC (current situation) and two DCs options. The rest of the options are dropped from the results table in order to narrow down the alternative scenarios. Best result for each objective and for different value of price elasticity are bolded on the table.

As estimated by their definition, by increasing price elasticity coefficient, sales volume is also dramatically impacted by price changes. Due to the higher sales volume changes with higher value of the coefficient, the total profit is higher when the price is decreased and the total profit is lower when the price is increased.

The sales volume is always maximized when the price is decreased as much as possible and two DCs are opened concurrently regardless of the value of price elasticity coefficients. The figures below represent how the distance function changes against the different value of price elasticity coefficients for current situation and for two DC options.

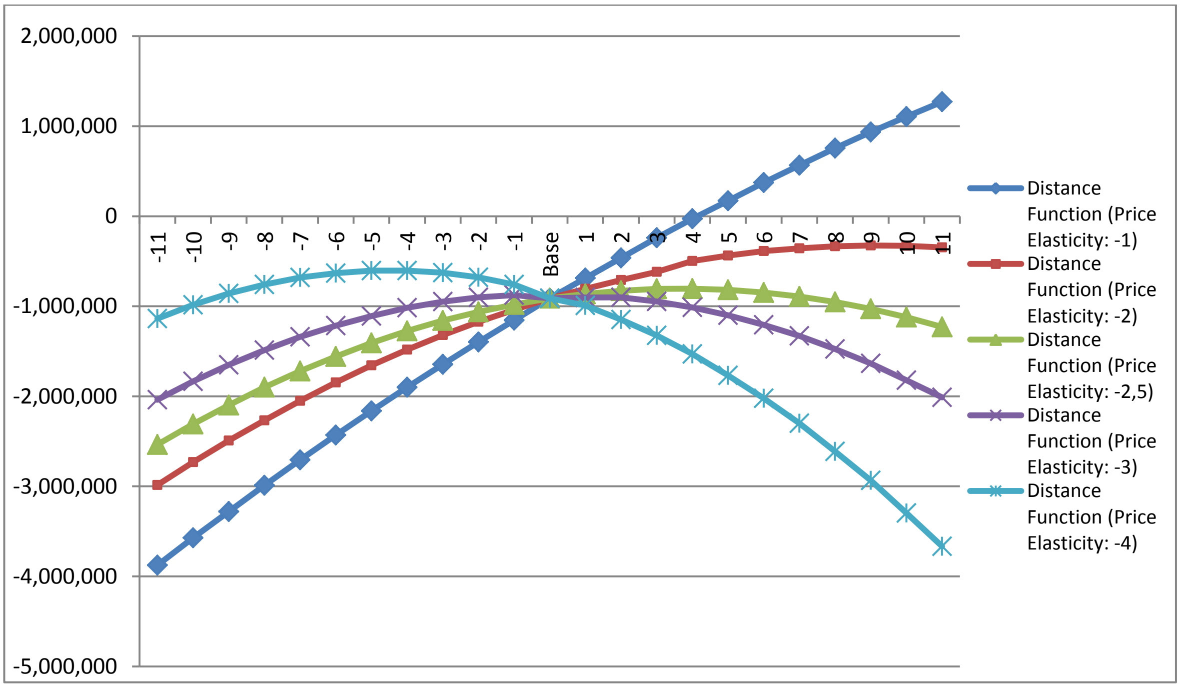

Figure 5-8. Distance function – price changes for different value of price elasticity coefficients for two DCs options

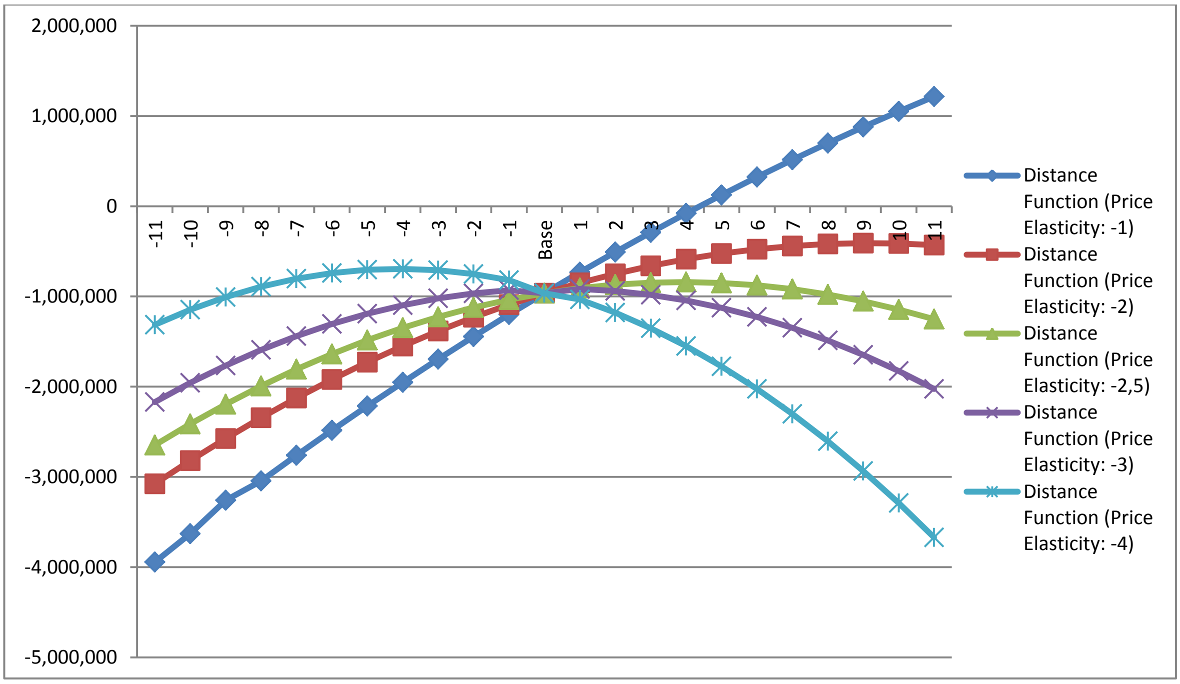

Figure 5-9. Distance function – price changes for different value of price elasticity coefficients for current situation (one DC options)

As remembered in our base scenario, both the profit and sales volume decreases after the price increase level of 11 %. That point changes due to price coefficient value. By the increase of the value of the price elasticity coefficient that point is also decreased. That is, that point is more than 11 % for price elasticity coefficient of "1", the point is only 3 %, for the price elasticity coefficient of "4".

Another important conclusion may be drawn from the analysis of the distance function which is a combination of both sales volume and the profit. As the price coefficient value increases from 1 to 4, the highest value of distance function is acquired at lower level of price increases. Table 5-16 represents the sensitivity of the distance function with respect to the price elasticity coefficients.

Table 5-16. Distance Function Results with respect to the Price Elasticity coefficient.

Price Elasticity Coefficient	-1	-2	-2,5	-3	-4
Price at Optimum Distance Point	Above + 11 %	9 %	4 %	2 %	- 5 %
# of DC at optimum Distance Point	2 DCs	2 DCs	2 DCs	2 DCs	2 DCs

Table 5-16 shows that, regardless of the price change and the price elasticity coefficient, the best highest distance value is acquired when two DCs are opened concurrently. Because, opening an additional DC has positive impact on sales volume; even though it has negative impact on profitability. Since the impact on sales volume is more than influence on profitability, the distance function gets higher.

Another important conclusion which may be derived from the analysis is that the developed model is capable of representing the changes on the SC performance objectives (risk value, profitability, total sales volume) as the price elasticity coefficient changes. As remembered, the main objective of the model is to add the attraction function's impact (distance from the customer zone) on the sales volume as well as on other SC performance objectives. As seen on above figures , regardless of the coefficient value, model results represent changes on sales volume and other performance metrics change with respect to the price elasticity coefficient. Besides that, strategic level SC network decisions, such as the number and location of DCs, are not influenced by the value of the coefficient even though optimum price level needs to be deliberately analyzed on the market in order to figure out distance value maximizing point.

5.4.2. One – Day Replenishment Coverage Area Effect Coefficient (β)

Within the proposed model, it is assumed that, in case, the distance between DC and retail outlet is less than 600 kilometers that will have positive impact on the demand with a predefined coefficient (β). That coefficient is assumed to be 0.1. However, that predetermined coefficient value depends on only estimates of company experts. Therefore, it would be required to analyze the sensitivity of the model results with respect to different values of one day replenishment coverage area effect coefficient.

Table 5-17 represents the model results for different values of the coefficient (0.05, 0.1, 0.2). Like changes on the price elasticity coefficients, changes on the coverage effect coefficient do not have influence on the risk value, so changes on risk value are not presented on the table.

Table 5-17. Model results for different One day replenishment coverage effect Coefficients (β)

Price Change (%)	Number of DC(s)	Demand Coverage Effect Coefficient (β)	Risk Value	Total Profit (TL)	Total Number of Sales	Distance Function	Demand Coverage Effect Coefficient (β)	Total Profit (TL)	Total Number of Sales	Distance Function	Demand Coverage Effect Coefficient (β)	Total Profit (TL)	Total Number of Sales	Distance Function
-11	1	0.05	0.965	2,047,448	2,821,353	-2,919,840	0.1	2,177,264	2,892,193	-2,648,350	0.2	2,436,898	3,033,871	-2,105,360
-11	2	0.05	0.999	1,903,955	**2,929,188**	-2,847,670	0.1	2,054,143	**3,009,489**	-2,536,880	0.2	2,350,518	**3,172,459**	-1,914,560
-10	1	0.05	0.965	2,379,278	2,767,422	-2,695,880	0.1	2,519,822	2,838,261	-2,413,650	0.2	2,800,910	2,979,940	-1,849,210
-10	2	0.05	0.999	2,224,521	2,873,087	-2,639,300	0.1	2,392,013	2,954,265	-2,309,460	0.2	2,712,604	3,116,621	-1,664,150
-9	1	0.05	0.965	2,694,800	2,713,490	-2,488,220	0.1	2,846,071	2,784,329	-2,195,270	0.2	3,148,613	2,926,008	-1,609,370
-9	2	0.05	0.999	2,540,441	2,817,511	-2,434,540	0.1	2,708,306	2,901,529	-2,098,630	0.2	3,060,321	3,060,782	-1,428,110
-8	1	0.05	0.965	2,994,013	2,659,558	-2,296,870	0.1	3,156,011	2,730,398	-1,993,190	0.2	3,480,007	2,872,076	-1,385,840
-8	2	0.05	0.999	2,834,220	2,761,673	-2,252,430	0.1	3,017,860	2,845,920	-1,900,300	0.2	3,391,625	3,004,944	-1,208,480
-7	1	0.05	0.965	3,276,917	2,605,627	-2,121,830	0.1	3,449,642	2,676,466	-1,807,420	0.2	3,795,092	2,818,145	-1,178,620
-7	2	0.05	0.999	3,111,326	2,707,140	-2,084,390	0.1	3,309,545	2,790,082	-1,720,290	0.2	3,705,835	2,947,881	-1.008,401
-6	1	0.05	0.965	3,543,512	2,551,695	-1,963,100	0.1	3,726,964	2,622,534	-1,637,970	0.2	4,093,868	2,764,213	-987,704
-6	2	0.05	0.999	3,371,821	2,651,985	-1,934,210	0.1	3,582,321	2,734,785	-1,558,110	0.2	4,006,042	2,893,300	-817,356
-5	1	0.05	0.965	3,793,798	2,497,763	-1,820,670	0.1	3,987,977	2,568,603	-1,484,820	0.2	4,376,335	2,710,281	-813,101
-5	2	0.05	0.999	3,620,950	2,596,443	-1,796,160	0.1	3,844,937	2,679,040	-1,406,980	0.2	4,288,662	2,842,212	-636,911
-4	1	0.05	0.965	4,027,775	2,443,832	-1,694,560	0.1	4,232,681	2,514,671	-1,347,980	0.2	4,642,493	2,656,350	-654,806
-4	2	0.05	0.999	3,849,908	2,540,605	-1,678,880	0.1	4,087,804	2,624,330	-1,273,530	0.2	4,554,369	2,788,254	-479,121
-3	1	0.05	0.965	4,245,443	2,389,900	-1,584,750	0.1	4,461,076	2,460,739	-1,227,440	0.2	4,892,342	2,602,418	-512,820
-3	2	0.05	0.999	4,062,580	2,485,256	-1,576,910	0.1	4,314,285	2,568,492	-1,158,730	0.2	4,803,344	2,732,416	-341,822
-2	1	0.05	0.965	4,446,802	2,335,968	-1,491,260	0.1	4,673,162	2,406,808	-1,123,220	0.2	5,125,882	2,548,486	-387,143
-2	2	0.05	0.999	4,258,938	2,429,418	-1,492,220	0.1	4,522,868	2,512,653	-1,061,820	0.2	5,045,058	2,673,562	-217,817
-1	1	0.05	0.965	4,631,853	2,282,037	-1,414,070	0.1	4,868,939	2,352,876	-1,035,310	0.2	5,343,113	2,494,555	-277,775
-1	2	0.05	0.999	4,438,986	2,373,580	-1,423,850	0.1	4,715,142	2,456,815	-981,226	0.2	5,263,113	2,622,840	-101,206
0	1	0.05	0.965	4,800,594	2,228,105	-1,353,190	0.1	5,048,408	2,298,944	-963,701	0.2	5,544,035	2,440,623	-184,717
0	2	0.05	0.999	4,602,726	2,317,742	-1,371,790	0.1	4,891,933	2,402,777	-912,511	0.2	5,466,433	2,568,427	-6.713
1	1	0.05	0.965	4,953,026	2,174,174	-1,308,630	0.1	5,211,567	2,245,013	-908,405	0.2	5,728,649	2,386,691	-107,967
1	2	0.05	0.999	4,750,157	2,261,903	-1,336,030	0.1	5,051,779	2,346,939	-864,341	0.2	5,650,608	2,512,588	55,786
2	1	0.05	0.965	5,089,149	2,120,242	-1,280,370	0.1	5,358,417	2,191,081	-869,418	0.2	5,896,953	2,332,760	-47.527
2	2	0.05	0.999	4,881,279	2,206,065	-1,316,590	0.1	5,197,643	2,292,318	-827,719	0.2	5,818,475	2,456,750	121,976
3	1	0.05	0.965	5,208,964	2,066,310	**-1,268,410**	0.1	5,488,959	2,137,149	-846,740	0.2	6,048,948	2,278,828	-3.395
3	2	0.05	0.999	4,996,091	2,150,227	-1,313,450	0.1	5,328,699	2,237,044	**-807,211**	0.2	5,968,735	2,403,665	156,066
4	1	0.05	0.965	5,312,469	2,012,379	-1,272,770	0.1	5,603,191	2,083,218	-840,371	0.2	6,184,635	2,224,896	24,428
4	2	0.05	0.999	5,094,595	2,094,389	-1,326,630	0.1	5,441,562	2,181,503	-805,430	0.2	5,908,482	2,450,165	198,813
5	1	0.05	0.965	5,399,665	1,958,447	-1,293,440	0.1	5,701,114	2,029,286	-850,311	0.2	6,304,012	2,170,965	35,942
5	2	0.05	0.999	5,186,438	2,041,046	-1,341,470	0.1	5,539,796	2,126,486	-817,230	0.2	6,043,853	2,394,327	222,508
6	1	0.05	0.965	5,470,553	1,904,515	-1,330,420	0.1	5,782,729	1,975,354	-876,560	0.2	6,407,080	2,117,033	31,148
6	2	0.05	0.999	5,252,539	1,985,068	-1,387,320	0.1	5,621,910	2,070,200	-847,688	0.2	6,159,895	2,338,489	**226,873**
7	1	0.05	0.965	5,525,131	1,850,584	-1,383,700	0.1	5,848,034	1,921,423	-919,118	0.2	6,493,840	2,063,101	10,044
7	2	0.05	0.999	5,307,003	1,930,239	-1,442,520	0.1	5,687,015	2,015,344	-892,295	0.2	6,265,669	2,282,651	220,971
8	1	0.05	0.965	5,563,401	1,796,652	-1,453,290	0.1	5,897,031	1,867,491	-977,985	0.2	6,564,290	2,009,170	-27.369
8	2	0.05	0.999	5,340,711	1,874,401	-1,520,490	0.1	5,735,773	1,961,138	-951,950	0.2	6,352,113	2,226,812	195,739
9	1	0.05	0.965	5,585,361	1,742,720	-1,539,200	0.1	5,929,718	1,813,560	-1,053,160	0.2	6,618,432	1,955,238	-81,090
9	2	0.05	0.999	5,358,109	1,818,562	-1,614,760	0.1	5,769,508	1,906,141	-1,028,210	0.2	6,422,248	2,170,974	154,197
10	1	0.05	0.965	5,591,013	2,083,218	-1,641,410	0.1	5,946,097	1,759,628	-1,144,650	0.2	6,656,265	1,901,306	-151,121
10	2	0.05	0.999	5,359,199	1,762,724	-1,725,350	0.1	5,787,622	1,850,741	-1,120,890	0.2	6,476,075	2,115,136	96,347
11	1	0.05	0.965	**5,580,356**	1,634,857	-1,759,930	0.1	**5,946,167**	1,705,696	-1,252,440	0.2	**6,677,788**	1,847,375	-237,460
11	2	0.05	0.999	5,351,984	1,705,886	-1,846,240	0.1	5,788,433	1,796,138	-1,229,290	0.2	6,513,592	2,059,298	22,188

Best results for each objective and for different value of price elasticity are summarized on below table.

Table 5-18. Summary of optimum results for different values of Coverage Area Effect Coefficient (β)

Scenario	Number of DCs	Optimum Price	Distance Function Value
β: 0.05	1	+ % 3	-1.268.410
β: 0.1	2	+ % 3	-807.211
β: 0.2	2	+ % 6	226.873

The results show that the demand coverage coefficient has substantial impact on sales volume and subsequently on the profitability of SC. The results also show that how much potential the one day replenishment coverage effect program has for the profitability of the chain and the sales volume of the company. Therefore, after implementing this program, firm needs to evaluate the results and try to increase the value of the coefficient by promotions, advertisement etc.

It may have also been concluded that with higher values of coefficient, opening an additional DC gets more profitable for the company. In our base scenario, opening an additional DC has negative impact on profitability; however, it has positive influence on sales volume. As seen on the results table, with 0.2 value of the coefficient, profitability is not negatively influenced by opening second DC. Those results supports the idea that adding attraction function to the demand model may change the optimal solution the model generates and strategic level SC network decisions.

The results also show that the performance metrics such as profitability and sales volume are quite sensitive to the values of coverage effect coefficient. However; the developed model is capable of representing changes on performance objectives of the models as the coverage coefficient value changes.

In this section of the sensitivity analysis, only the sensitivity of the model results with respect to different values of one day replenishment coverage area effect coefficient is analyzed. However, the model may also be sensitive to how the coverage area is defined; that is, how the model results change when it is assumed that the firm may make one day replenishment only for the distance below 300 kilometers, 450 kilometers or some other distances. Sensitivity of the model to the definition of the coverage area is not analyzed in the study in order to keep the study focused on core definitions and may also be subject to further studies.

5.4.3. Risk Factors (μ, δ, φ)

After analyzing the sensitivity of the objectives with respect to the coefficients which have substantial impact on demand, disruption probabilities of risk factor will be analyzed in order to figure out how model outputs are impacted by the changes on those probabilities. In the base scenario, disruption probabilities are utilized as follows;

μ (disruption probability at transporting goods from suppliers to DC): 0.5 %.

δ (disruption probability at handling goods at any DC): 1 %.

φ (disruption probability at transporting goods from DC to customer zones): 2 %.

Two more scenarios are created to analyze the sensitivity of the model objectives. Table 5-19 presents those two new scenarios.

Table 5-19. Risk Factor Probabilities - Sensitivity Analysis Scenarios

Scenario	μ (%)	δ (%)	Φ (%)
Base Scenario	0.5	1	2
Scenario I	0.25	0.5	1
Scenario II	1	2	3

Table 5-20 represents the model results with respect to different disruption probability scenarios defined on Table 5-19. Best results for each objective on each scenario are highlighted also on the table.

Table 5-20. Model results for different disruption probability scenarios (μ, δ, φ)

Price Change (%)	Number of DC(s)	Scenario	Risk Value	Total Profit (TL)	Total Number of Sales	Distance Function	Scenario	Risk Value	Total Profit (TL)	Total Number of Sales	Distance Function	Scenario	Risk Value	Total Profit (TL)	Total Number of Sales	Distance Function
-11	1	I	0.983	2,398,893	2,943,839	-2,323,430	Base	0.965	2,177,264	2,892,193	-2,648,350	II	0.941	1,865,425	2,819,525	-3,105,520
-11	2	I	1.000	2,058,827	**3,011,289**	-2,528,590	Base	0.999	2,054,143	**3,009,489**	-2,536,880	II	0.999	2,038,301	**3,007,993**	-2,555,710
-10	1	I	0.983	2,737,318	2,888,944	-2,094,790	Base	0.965	2,519,822	2,838,261	-2,413,650	II	0.941	2,213,798	2,766,948	-2,862,300
-10	2	I	1.000	2,392,966	2,955,953	-2,305,130	Base	0.999	2,392,013	2,954,265	-2,309,460	II	0.999	2,377,280	2,951,680	-2,329,360
-9	1	I	0.983	3,059,434	2,834,050	-1,882,460	Base	0.965	2,846,071	2,784,329	-2,195,270	II	0.941	2,545,861	2,714,371	-2,635,390
-9	2	I	1.000	2,716,526	2,901,020	-2,091,430	Base	0.999	2,708,306	2,901,529	-2,098,630	II	0.999	2,699,142	2,896,415	-2,118,030
-8	1	I	0.983	3,365,242	2,779,155	1,686,450	Base	0.965	3,156,011	2,730,398	-1,993,190	II	0.941	2,861,616	2,661,795	-2,424,790
-8	2	I	1.000	3,020,148	2,846,984	-1,895,880	Base	0.999	3,017,860	2,845,920	-1,900,300	II	0.999	3,007,174	2,843,430	-1,915,960
-7	1	I	0.983	3,654,740	2,724,260	-1,506,740	Base	0.965	3,449,642	2,676,466	-1,807,420	II	0.941	3,161,062	2,609,218	-2,230,500
-7	2	I	1.000	3,314,261	2,791,181	-1,713,380	Base	0.999	3,309,545	2,790,082	-1,720,290	II	0.999	3,299,068	2,787,640	-1,735,650
-6	1	I	0.983	3,927,929	2,669,365	-1,343,340	Base	0.965	3,726,964	2,622,534	-1,637,970	II	0.941	3,444,199	2,556,642	-2,052,520
-6	2	I	1.000	3,591,020	2,730,837	-1,557,300	Base	0.999	3,582,321	2,734,785	-1,558,110	II	0.999	3,576,127	2,727,373	-1,579,120
-5	1	I	0.983	4,184,809	2,614,471	-1,196,250	Base	0.965	3,987,977	2,568,603	-1,484,820	II	0.941	3,711,027	2,504,065	-1,890,840
-5	2	I	1.000	3,850,161	2,676,750	-1,406,340	Base	0.999	3,844,937	2,679,040	-1,406,980	II	0.999	3,835,570	2,673,355	-1,427,720
-4	1	I	0.983	4,425,381	2,559,576	-1,065,470	Base	0.965	4,232,681	2,514,671	-1,347,980	II	0.941	3,961,546	2,451,488	-1,745,480
-4	2	I	1.000	4,092,240	2,625,363	-1,267,030	Base	0.999	4,087,804	2,624,330	-1,273,530	II	0.999	4,077,950	2,622,033	-1,287,980
-3	1	I	0.983	4,649,643	2,504,681	-950,993	Base	0.965	4,461,076	2,460,739	-1,227,440	II	0.941	4,195,756	2,398,912	-1,616,420
-3	2	I	1.000	4,318,626	2,569,503	-1,152,370	Base	0.999	4,314,285	2,568,492	-1,158,730	II	0.999	4,304,640	2,566,244	-1,172,870
-2	1	I	0.983	4,857,596	2,449,786	-852,829	Base	0.965	4,673,162	2,406,808	-1,123,220	II	0.941	4,413,657	2,346,335	-1,503,670
-2	2	I	1.000	4,527,115	2,513,643	-1,055,600	Base	0.999	4,522,868	2,512,653	-1,061,820	II	0.999	4,513,433	2,510,455	-1,075,660
-1	1	I	0.983	5,049,241	2,394,892	-770,974	Base	0.965	4,868,939	2,352,876	-1,035,310	II	0.941	4,615,249	2,293,759	-1,407,230
-1	2	I	1.000	4,717,805	2,457,783	-976,627	Base	0.999	4,715,142	2,456,815	-981,226	II	0.999	4,704,427	2,454,665	-996,240
Base Price	1	I	0.983	5,224,576	2,339,997	-705,428	Base	0.965	5,048,408	2,298,944	-963,701	II	0.941	4,800,533	2,241,182	-1,327,100
Base Price	2	I	1.000	4,897,679	2,400,720	-910,879	Base	0.999	4,891,933	2,402,777	-912,511	II	0.999	4,882,910	2,400,675	-925,738
1	1	I	0.983	5,383,603	2,285,102	-656,191	Base	0.965	5,211,567	2,245,013	-908,405	II	0.941	4,969,507	2,188,605	-1,263,280
1	2	I	1.000	5,052,840	2,347,042	-863,075	Base	0.999	5,051,779	2,346,939	-864,341	II	0.999	5,040,064	2,344,065	-881,805
2	1	I	0.983	5,526,320	2,230,208	-623,263	Base	0.965	5,358,417	2,191,081	-869,418	II	0.941	5,122,172	2,136,029	-1,215,770
2	2	I	1.000	5,199,189	2,292,003	-826,802	Base	0.999	5,197,643	2,292,318	-827,719	II	0.999	5,189,972	2,290,086	-839,854
3	1	I	0.983	5,652,729	2,175,313	-606,644	Base	0.965	5,488,959	2,137,149	-846,740	II	0.941	5,258,528	2,083,452	-1,184,570
3	2	I	1.000	5,332,430	2,234,517	-808,535	Base	0.999	5,328,699	2,237,044	-807,211	II	0.999	5,320,299	2,235,086	-819,526
4	1	I	0.983	5,762,828	2,120,418	**-606,333**	Base	0.965	5,603,191	2,083,218	-840,371	II	0.941	5,378,576	2,030,876	-1,169,670
4	2	I	1.000	5,447,032	2,178,424	-806,119	Base	0.999	5,441,562	2,181,503	**-805,430**	II	0.999	5,432,656	2,179,833	**-817,677**
5	1	I	0.983	5,856,619	2,065,523	-622,332	Base	0.965	5,701,114	2,029,286	-850,311	II	0.941	5,482,314	1,978,299	-1,171,090
5	2	I	1.000	5,543,390	2,127,324	-811,960	Base	0.999	5,539,796	2,126,486	-817,230	II	0.999	5,531,810	2,124,625	-828,937
6	1	I	0.983	5,934,101	2,010,629	-654,640	Base	0.965	5,782,729	1,975,354	-876,560	II	0.941	5,569,743	1,925,722	-1,188,810
6	2	I	1.000	5,625,411	2,071,016	-842,555	Base	0.999	5,621,910	2,070,200	-847,688	II	0.999	5,614,131	2,068,389	-859,090
7	1	I	0.983	5,995,273	1,955,734	-703,257	Base	0.965	5,848,034	1,921,423	-919,118	II	0.941	5,640,864	1,873,146	-1,222,840
7	2	I	1.000	5,680,811	2,014,782	-899,624	Base	0.999	5,687,015	2,015,344	-892,295	II	0.999	5,677,373	2,014,037	-904,551
8	1	I	0.983	6,040,137	1,900,839	-768,182	Base	0.965	5,897,031	1,867,491	-977,985	II	0.941	5,695,675	1,820,569	-1,273,180
8	2	I	1.000	5,730,328	1,959,743	-960,184	Base	0.999	5,735,773	1,961,138	-951,950	II	0.999	5,723,833	1,958,247	-969,670
9	1	I	0.983	6,068,692	1,845,945	-849,417	Base	0.965	5,929,718	1,813,560	-1,053,160	II	0.941	5,734,178	1,767,993	-1,339,840
9	2	I	1.000	5,772,730	1,906,892	-1,023,480	Base	0.999	5,769,508	1,906,141	-1,028,210	II	0.999	5,761,424	1,904,471	-1,039,630
10	1	I	0.983	6,080,938	1,791,050	-946,961	Base	0.965	5,946,097	1,759,628	-1,144,650	II	0.941	5,756,371	1,715,416	-1,422,800
10	2	I	1.000	5,790,752	1,851,470	-1,116,310	Base	0.999	5,787,622	1,850,741	-1,120,890	II	0.999	5,780,670	1,849,122	-1,131,080
11	1	I	0.983	**6,076,875**	1,736,155	-1,060,810	Base	0.965	**5,946,167**	1,705,696	-1,252,440	II	0.941	5,762,256	1,662,839	-1,522,060
11	2	I	1.000	5,788,608	1,796,163	-1,229,070	Base	0.999	5,788,433	1,796,138	-1,229,290	II	0.999	**5,778,830**	1,793,885	-1,243,400

Below Table 5-21 summarizes the optimal solution for each scenario and depicts how total profit, total volume of sales and distance function value changes through scenarios.

Table 5-21. Summary of optimum results for different values of disruption probabilities

Scenario	Number of DCs	Optimum Price	Risk Value	Total Profit (TL)	Total # of Sales	Distance Function Value
Scenario I	1	+ % 4	0.983	5.762.828	2.120.418	- 606.333
Base	2	+ % 4	0.999	5.441.562	2.181.503	- 805.430
Scenario II	2	+ % 4	0.999	5.432.656	2.179.833	- 817.677

As seen on Table 5-20 and Table 5-21, both sales volume and profitability of SC of SC are influenced by the disruption probabilities due to the lost sales volume and costs of lost sales. By increasing the disruption probabilities, lost sales volume and costs of lost sales also increases. Even though both profitability and sales values are influenced by the disruption probabilities, the results follow pretty much same pattern through various scenarios defined on Table 5-19.

Results also show that when the probabilities are higher, as in Scenario II, opening an additional DC gets more profitable. Unlike Scenario II, the profit difference between current situation and two DC options are so high that the distance function results are also lower in two DC options, in Scenario I.

In conclusion, analysis of the three different scenarios with different disruption probabilities showed that the proposed model reflects the changes on the objectives through different disruption probability scenarios. As the results change, the decisions does not necessarily change since the results follow same patterns through scenarios. Results also showed that controlling and lowering disruption probabilities through the network as much as possible is crucial for the company’s objectives since they have substantial negative impact on all objectives; that is risk value, sales volume and the profitability of SC. Lowering of disruption probabilities is also very important to serve customers uninterruptedly.

5.4.4. Relative Weights of the Objectives (d1, d2)

Last coefficients which will be analyzed in sensitivity analysis section are the relative importance of the performance objectives (total profit - d_1 and sales volume - d_2) in distance function formula.

As it may have been remembered that only two out of three objectives are utilized in distance function and presented to decision makers along with risk values. As it may have also been remembered that sales volume is multiplied by two in order to rescale objectives to be at the same level since the profit are about two times more than the sales volume in base scenario at base price level. Other than rescaling, relative weights of the two separate objectives are assumed to be same. Therefore, in that subsection, how the value of distance function changes with respect to the changes on relative importance of the objectives is analyzed.

Other than base scenario, two more scenarios are created for the sensitivity analysis. Table 5-22 defines those scenarios.

Table 5-22. Relative weights of the objectives

Scenario	d_1 (Multiplied by)	d_2 (Multiplied by)
Base Scenario	2	1
Scenario I	1	1
Scenario II	4	1

Table 5-23 presents the model results for different scenarios defined on Table 5-22. Table shows that the distance values in scenario I and II change due to changing distance function formulation; however, the sales volume and total profit does not substantially change. Even for current situation with one - DC options, model finds the exactly same solution. Meantime, for two – DC options, the model sometimes find the same solution or very close solutions. Therefore, it may be concluded from the results that for price and number of DC alternatives model finds almost the same solution with different values of relative weights of the objectives.

Table 5-23. Model results for different relative importance of the objectives ($d_1 – d_2$)

Price Change (%)	Number of DC(s)	Risk Value	Scenario	Total Profit (TL)	Total Number of Sales	Distance Function	Scenario	Total Profit (TL)	Total Number of Sales	Distance Function	Scenario	Total Profit (TL)	Total Number of Sales	Distance Function
-11	1	0,965	I	2.177.264	2.892.193	-3.010.540	Base	2.177.264	2.892.193	-2.648.350	II	2.177.264	2.892.193	-1.923.960
-11	2	0,999	I	2.054.037	**3.007.473**	-3.018.490	Base	2.054.143	**3.009.489**	-2.536.880	II	2.047.769	**3.010.628**	-1.579.720
-10	1	0,965	I	2.519.822	2.838.261	-2.721.920	Base	2.519.822	2.838.261	-2.413.650	II	2.519.822	2.838.261	-1.797.130
-10	2	0,999	I	2.390.154	2.950.966	-2.738.880	Base	2.392.013	2.954.265	-2.309.460	II	2.383.260	2.956.835	-1.459.400
-9	1	0,965	I	2.846.071	2.784.329	-2.449.600	Base	2.846.071	2.784.329	-2.195.270	II	2.846.071	2.784.329	-1.686.610
-9	2	0,999	I	2.711.623	2.899.878	-2.468.500	Base	2.708.306	2.901.529	-2.098.630	II	2.711.623	2.899.878	-1.358.860
-8	1	0,965	I	3.156.011	2.730.398	-2.193.590	Base	3.156.011	2.730.398	-1.993.190	II	3.156.011	2.730.398	-1.592.400
-8	2	0,999	I	3.015.337	2.845.863	-2.218.800	Base	3.017.860	2.845.920	-1.900.300	II	3.017.860	2.845.920	-1.268.460
-7	1	0,965	I	3.449.642	2.676.466	-1.953.890	Base	3.449.642	2.676.466	-1.807.420	II	3.449.642	2.676.466	-1.514.490
-7	2	0,999	I	3.307.915	2.783.965	-1.988.120	Base	3.309.545	2.790.082	-1.720.290	II	3.305.290	2.790.250	-1.203.710
-6	1	0,965	I	3.726.964	2.622.534	-1.730.500	Base	3.726.964	2.622.534	-1.637.970	II	3.726.964	2.622.534	-1.452.900
-6	2	0,999	I	3.582.285	2.733.169	-1.764.550	Base	3.582.321	2.734.785	-1.558.110	II	3.582.321	2.734.785	-1.148.540
-5	1	0,965	I	3.987.977	2.568.603	-1.523.420	Base	3.987.977	2.568.603	-1.484.820	II	3.987.977	2.568.603	-1.407.610
-5	2	0,999	I	3.845.632	2.675.696	-1.558.670	Base	3.844.937	2.679.040	-1.406.980	II	3.844.937	2.679.040	-1.108.900
-4	1	0,965	I	4.232.681	2.514.671	-1.332.650	Base	4.232.681	2.514.671	-1.347.980	II	4.232.681	2.514.671	-1.378.630
-4	2	0,999	I	4.087.804	2.624.330	-1.367.870	Base	4.087.804	2.624.330	-1.273.530	II	4.087.804	2.624.330	-1.084.870
-3	1	0,965	I	4.461.076	2.460.739	-1.158.180	Base	4.461.076	2.460.739	-1.227.440	II	4.461.076	2.460.739	-1.365.960
-3	2	0,999	I	4.314.285	2.568.492	-1.197.220	Base	4.314.285	2.568.492	-1.158.730	II	4.312.729	2.568.492	**-1.083.300**
-2	1	0,965	I	4.673.162	2.406.808	-1.000.030	Base	4.673.162	2.406.808	-1.123.220	II	4.673.162	2.406.808	-1.369.600
-2	2	0,999	I	4.522.868	2.512.653	-1.044.480	Base	4.522.868	2.512.653	-1.061.820	II	4.521.345	2.512.653	-1.098.040
-1	1	0,965	I	4.868.939	2.352.876	-858.183	Base	4.868.939	2.352.876	-1.035.310	II	4.868.939	2.352.876	-1.389.550
-1	2	0,999	I	4.716.191	2.449.907	-913.901	Base	4.715.142	2.456.815	-981.226	II	4.713.652	2.456.815	-1.129.080
Base Price	1	0,965	I	5.048.408	2.298.944	-732.646	Base	5.048.408	2.298.944	-963.701	II	5.048.408	2.298.944	-1.425.810
Base Price	2	0,999	I	4.891.107	2.400.977	-787.915	Base	4.891.933	2.402.777	-912.511	II	4.891.933	2.402.777	-1.166.960
1	1	0,965	I	5.211.567	2.245.013	-623.419	Base	5.211.567	2.245.013	-908.405	II	5.211.567	2.245.013	-1.478.380
1	2	0,999	I	5.053.595	2.347.601	-678.802	Base	5.051.779	2.346.939	-864.341	II	5.053.595	2.347.601	-1.226.000
2	1	0,965	I	5.358.417	2.191.081	-530.500	Base	5.358.417	2.191.081	-869.418	II	5.358.417	2.191.081	-1.547.260
2	2	0,999	I	5.198.222	2.292.179	-589.597	Base	5.197.643	2.292.318	-827.719	II	5.197.643	2.292.318	-1.303.080
3	1	0,965	I	5.488.959	2.137.149	-453.890	Base	5.488.959	2.137.149	-846.740	II	5.488.959	2.137.149	-1.632.440
3	2	0,999	I	5.328.648	2.233.637	-517.714	Base	5.328.699	2.237.044	-807.211	II	5.328.699	2.237.044	-1.393.120
4	1	0,965	I	5.603.191	2.083.218	-393.590	Base	5.603.191	2.083.218	-840.371	II	5.603.191	2.083.218	-1.733.940
4	2	0,999	I	5.441.562	2.181.503	-456.933	Base	5.441.562	2.181.503	**-805.430**	II	5.441.562	2.181.503	-1.502.420
5	1	0,965	I	5.701.114	2.029.286	-349.598	Base	5.701.114	2.029.286	-850.311	II	5.701.114	2.029.286	-1.851.740
5	2	0,999	I	5.539.796	2.126.486	-413.717	Base	5.539.796	2.126.486	-817.230	II	5.540.193	2.126.613	-1.623.350
6	1	0,965	I	5.782.729	1.975.354	-321.915	Base	5.782.729	1.975.354	-876.560	II	5.782.729	1.975.354	-1.985.850
6	2	0,999	I	5.621.910	2.070.200	-387.889	Base	5.621.910	2.070.200	-847.688	II	5.621.910	2.070.200	-1.767.290
7	1	0,965	I	5.848.034	1.921.423	**-310.541**	Base	5.848.034	1.921.423	-919.118	II	5.848.034	1.921.423	-2.136.270
7	2	0,999	I	5.687.015	2.015.344	-377.639	Base	5.687.015	2.015.344	-892.295	II	5.685.654	2.016.186	-1.919.600
8	1	0,965	I	5.897.031	1.867.491	-315.477	Base	5.897.031	1.867.491	-977.985	II	5.897.031	1.867.491	-2.303.000
8	2	0,999	I	5.731.194	1.959.962	-388.843	Base	5.735.773	1.961.138	-951.950	II	5.735.773	1.961.138	-2.089.670
9	1	0,965	I	5.929.718	1.813.560	-336.721	Base	5.929.718	1.813.560	-1.053.160	II	5.929.718	1.813.560	-2.486.040
9	2	0,999	I	5.770.825	1.899.214	-409.959	Base	5.769.508	1.906.141	-1.028.210	II	5.769.508	1.906.141	-2.275.920
10	1	0,965	I	5.946.097	1.759.628	-374.274	Base	5.946.097	1.759.628	-1.144.650	II	5.946.097	1.759.628	-2.685.390
10	2	0,999	I	5.787.622	1.850.741	-441.635	Base	5.787.622	1.850.741	-1.120.890	II	5.787.622	1.850.741	-2.479.410
11	1	0,965	I	**5.946.167**	1.705.696	-428.136	Base	**5.946.167**	1.705.696	-1.252.440	II	**5.946.167**	1.705.696	-2.901.050
11	2	0,999	I	5.785.572	1.795.456	-498.971	Base	5.788.433	1.796.138	-1.229.290	II	5.788.433	1.796.138	-2.697.010

Optimal solutions for each scenario are depicted on below table. Table also depicts that how optimal price level, total profit, total volume of sales and distance function value changes through scenarios.

Table 5-24. Summary of optimum results for different relative weights of objectives

Scenario	Number of DCs	Optimum Price	Risk Value	Total Profit (TL)	Total # of Sales	Distance Function Value
Scenario I	1	+ % 7	0.965	5.848.034	1.921.423	- 310.541
Base	2	+ % 4	0.999	5.441.562	2.181.503	- 805.430
Scenario II	2	- % 3	0.999	4.312.729	2.568.492	- 1.083.300

Even though best solution for each price change and number of DC options does not change substantially, the price which maximizes the distance value changes according to the relative weights of the objectives. When the relative weight of the sales volume increases, the mathematically optimal price level is decreased.

In conclusion, analysis of the three different scenarios with different relative weights of the objectives showed that the proposed model reflects the changes on the objectives through different scenarios. As the results change, SC based decisions such as number, location and the capacity of the DCs, demand fill rate and the network traffic does not necessarily change since the results follow same patterns through various scenarios.

5.4.5. Sensitivity Analysis– Managerial Implications

Several managerial implications may be derived from the sensitivity analysis presented above in details.

- Developed model represents the changes on the SC objectives such as profitability of SC and total sales volume with respect to the different value of price elasticity. Besides SC network optimization decisions, the model may also be used as decision support tool in making pricing decisions.

- Strategic level SC decision; that is opening an additional DC, capacity and location of DC(s); is not substantially influenced by the value of the price elasticity coefficient.

- Higher value of price elasticity coefficient may have negative influence on sales and eventually profits. Therefore, the firm may apply brand loyalty programs to decrease price elasticity coefficients in order to maximize its profits without substantially harming its total sales.

- The sensitivity analysis showed that the one day replenishment coverage program has very much potential on the profitability and the total sales volume of the company. Therefore, after implementing this program, firm need to evaluate the results and try to increase the value of the coefficient by awareness programs and promotions etc.

- The results of the sensitivity analysis on one day replenishment coverage effect coefficient also supported the idea that adding attraction function to the demand model may change the optimal solution the model generates and also may change strategic level SC network decisions.

- The risk factor sensitivity analysis showed that controlling and lowering disruption probabilities through the network as much as possible is crucial for the company’s success since lower disruption probabilities may lead to higher risk value, sales volume and profitability. That is also very important to serve customers uninterruptedly.

- Sensitivity analysis of the model with respect to the relative importance of various performance objectives in distance function formula showed that the proposed model reflects the changes on those objectives with respect to the relative importance of objectives. As the results change, SC based decisions such as number and location of the DCs, and the network traffic does not necessarily change since the results follow same patterns through various scenarios. However, price level maximizing the distance function decreases as relative importance of the profit decreases.

CHAPTER 6. CONCLUSIONS AND FURTHER RESEARCH SUGGESTIONS

The main purpose of this chapter is to summarize the findings and to present a brief overview of the dissertation study. On this chapter, basic conclusions are presented and the implications of those conclusions are discussed. At the end of the chapter, implications for further research are also presented.

This study aims to analyze and explore how strategic level SC network decisions such as number, location, and capacity of SC nodes impact sales volume and eventually impacts strategic level SC network decisions. Therefore, a new SC network optimization model on which the concept of SC network optimization modeling is simultaneously utilized with competitive facility location models is developed. Main distinguishing attribute of the developed SC network optimization model is simultaneously modeling how the closeness of the SC nodes to the customer zones impacts the competition (demand) within the market.

In the first part of the dissertation study, a detailed literature review on SC network optimization models, especially models developed during the last five years, is conducted. The detailed literature review showed that, in most of SC network optimization studies, the structure of the supply chain network is considerably simplified (e.g., a single product and a single location layer are usually assumed), and there is still need for more comprehensive models that capture simultaneously many aspects relevant to real-life problems such as the competition dynamics within the market.

Literature review also showed that almost all of the SC network optimization models ignore the impacts of SC network decisions on the customer demand. However, the physical network structure of a SC is one of the important factors impacting chain’s competitiveness, especially for the retail markets. On the other hand, competitive facility location problems model only distribution part of the SC even though they sometimes have some characteristics of SC networks and may analyze the rival chains existing in the market.

After conducting the literature review, in order to cover abovementioned gaps, a multi-objective SC network optimization model also incorporating competitive facility location problems is developed. The model is defined as multi objective since SC networks are multi objectives in their nature. The objectives utilized in the model are; profit maximization, sales maximization and SC risk minimization (riskvalue maximization). Besides, profit maximization, objective of the sales maximization is also utilized within the model since the model company also aims to increase its sales by reconfiguration of its SC network and probably by opening additional new Distribution Center (DC) or DCs. Third objective defined in the proposed model function is risk minimization. Path based risk formulation is utilized to calculate risk value. In path based formulation, possible disruptions at DCs, inbound and outbound transportation links are considered and formulated as the probability of disruption occurrence at SC network nodes and links.

The model is defined as Mixed Integer Linear Programming (MILP) model with three echelon SC network, multi products, and single term. The SC structure consists of three echelons; Suppliers, Distribution Centers and Customer Zones. In order to simplify the model, products are aggregated to limited number of product types to represent the whole product mix.

Nature of the developed model is deterministic. The unique unknown variable within the model is the demand. In order to model the demand, a simple demand model is utilized. The demand at each customer zone is assumed to be determined by the price and the attraction function. Attraction function is defined as the availability of same-day transportation from DC to Customer Zone. It is assumed that if the transportation from DC to Customer zone within the same day is possible, that will have a positive impact on the sales at the customer zone by a predetermined coefficient because of a new program of delivering the right color and right size product to the stores in one day.

In the model, “Total Profit” is defined as the “Total Costs” subtracted from “Total Revenue” generated within the network over the whole term. “Total Costs” includes different cost parameters; unit product costs, inbound and outbound transportation costs, fixed facility costs, and disruption costs (shortage costs). Inventory costs are defined as changing dependent on the number of DCs because of consolidation effect. Disruption costs are calculated as the multiplication of total sales by disruption probability of the whole SC network (lost sales), then multiplied by shortage costs coefficients. Lost sales dependent on the SC disruption probability are also taken into account when calculating “Total Sales”.

Then, the proposed model is applied to a real life problem of one of the leading ready – wear clothing companies, which is primarily based in Turkey. The company currently has only one DC in Istanbul. However, the number of sales points and the total sales volume of the company increased sharply, in recent years. It is considered that the firm needs to reconfigure its supply chain network and to decide whether or not to open additional DC or DCs in alternative locations; İzmir or Ankara.

In their retail stores, the company has very limited storage capacity since most of them are located within big shopping centers; malls. In current network configuration, the firm does not guarantee to transport the right size and color product within a day due to the huge distance between retail stores and single DC in İstanbul. It is assumed that the firm may guarantee to transport the requested products within a day to the stores which are not more than 600 kilometers away from DCs. That is defined as attraction function in the demand model of the network.

After building the model and defining the real life problem, the model is run and model results are generated. The results showed that the defined model is a powerful tool to show how the performance objectives change while changing the decision variables such as number, location, and capacities of DCs, network traffic decisions, demand fill rate, price etc. Some of the major conclusions drawn from the findings are presented below;

- The model is first solved as a profit maximization problem. In the optimal solution for profit maximization problem, the sales decreased by 26 %. Because of the competition within the market, the 26 % sales decrease is not acceptable by any firms. Besides sales decrease, the risk value of 0.965 is also high in optimal solution.

- Then, the model is solved as total sales maximization problem. In the optimal solution for sales maximization problem, total profit of the SC dropped below zero. Since SC does not generate profit, that is also not acceptable by any firms. Therefore, it has been concluded that modeling the problem as profit maximization or sales maximization does not generate required results and all three performance measures (profit, sales, risk) need to be simultaneously taken into account.

- The model is capable of capturing how the demand and the profit of the model company changes as the strategic level network configuration decisions change. The model is also capable of capturing how the SC network traffic needs to be modeled to maximize profit or sales volume or both SC objectives.

- The model results also showed that performance objectives of the model are substantially influenced by strategic level SC network decisions such as number and location of DCs, price change level etc. have substantial influence on all performance objectives. However, decisions such as SC network traffic decisions, DC – customer zone allocation, demand fill rate etc. have either minor or no influence on performance of the SC.

- The model is also utilized to model SC disruption risks. However, due to the multi-objective nature of the SC network, the model firm wants to maximize its profit, sales volume and SC risk value. In order to support decision making, the model is solved as a goal programming function. Distance maximization function of the model gives hints about the best solution for the firm's problem. However, the objectives in the distance function are rescaled and weighted by subjective weights, providing a list of optimal solution for each scenario will help DMs.

- The results also showed that including attraction function on the model substantially changes the performance objectives of the model. When the model proposes to open an additional DC, it generates around 5 % more sales volume due to the defined attraction function. However, the model results show that total profit is decreased due to the fixed DC costs, slightly increasing inventory holding costs, and slightly increasing transportation costs. That also generates more revenue; however, the revenue increase is not enough to cover cost increases. Therefore, in profit maximization problems, one DC options (current situation) are chosen. In a model, both capturing sales volume and profit, two DC solution is proposed to be chosen since sales volume increase is more than profit decrease.

After providing the optimal solution list for various number of DC and price change combinations, sensitivity of the model with respect to the some coefficients is analyzed in order to test whether the model generates similar results when some of the parameters within the model are changed. Several managerial implications may be derived from the sensitivity analysis;

- Developed model represents the changes on the SC objectives such as profitability of SC and sales volume with respect to the different value of price elasticity. Besides SC network optimization decisions, the model may also be used as decision support tool in making pricing decisions.

- Strategic level SC decision; that is opening an additional DC; is not substantially influenced by the value of the price elasticity coefficient. Price elasticity may have negative influence on sales and eventually profits. Therefore, the firm may apply brand loyalty programs to decrease price elasticity coefficients in order to maximize its profits without substantially harming its sales.

- The sensitivity analysis showed that the one day replenishment coverage program has very much potential on the profitability and the sales volume of the company. Therefore, after implementing this program, firm need to evaluate the results and try to increase the value of the coefficient by awareness programs and promotions etc.

- The risk factor sensitivity analysis showed that controlling and lowering disruption probabilities through SC nodes and links as much as possible is crucial for the company's success since lower disruption probabilities may lead to lower risks, higher sales volume and profitability. That is also very important to serve customers uninterruptedly.

- Sensitivity analysis of the model with respect to the relative importance of the objectives in distance function showed that the proposed model reflects the changes on the objectives with respect to the relative importance of those objectives. As the results change, SC based decisions such as number and location of the DCs, and the network traffic does not necessarily change since the results follow same patterns through various scenarios defined with different relative importance of the objectives.

The result of this study contributes to the Supply Chain Network Optimization model literature in several ways. First, the developed and analyzed model is the first SC network optimization model incorporating the changes in the demand, which is defined as subject to the both price change and distance from the end-customers and which is substantially influenced by strategic level SC network optimization model decisions. As explained in previous sections, there are some studies, in the current literature, modeling demand as product of competition factors such as price and competitor's price on the market. However, none of those models includes any attraction function such as distance from the customers, availability of the products etc. which are also subject to SC network modeling decisions on their models. Second, this model is also the first model simultaneously utilizing supply side risk analysis, demand functions and strategic level SC decisions. In every scenario, besides profit and the sales volume, how the supply side risk value of the network changes is also explored. Besides those contributions, the model also proved that single objective models may not generate acceptable results and showed that SC network optimization models need to be defined as multi-objective since SCs are multi-objective in their nature.

In order to enhance the developed model, first, the limitations of the model need to be explored. Since the model is the first model incorporating attraction function in demand model, only one type of attraction function (distance between DC and customer zone) is utilized within the model. Other attraction functions which are also influenced by SC network configuration decisions such as customer service level, availability of the stores at the demand point, distance between the store and the customers may be defined to explore how demand and eventually network configurations are influenced by those decisions.

Another major limitation of the study was concerning the lack of study on some major parameters of the model such as price elasticity coefficient and DC – customer zone one day replenishment availability effect coefficient. After a more deliberate study on the price elasticity on the market and after implementing one day replenishment program on the market, the study may be rerun with the real data gathered from the market on those coefficients.

Third limitation of the developed model is concerning the term of the model. The model is defined a single term model. Therefore, the model may be enhanced by including more than one term data in the analysis or the model may be enhanced by including possible future projections of the model company.

In order to explore the usefulness of the model, it model may also be applied to real life scenarios from other high competitive sectors such as food products, electronic products etc. SC network of the model firm was consisting of only three echelons. Defining a more complex SC network having more than 3 echelons and possibly including recycling centers, globalization issues etc. may also enhance the usefulness of the model.

In developed model, a simple, linear demand model including price elasticity and attraction function is defined for the sake of simplicity. A more complex demand model may be defined to analyze how SC network optimization decisions and model objectives change. Again, in order to keep the model simple, only supply side path based risk formulation is utilized. The model may be defined with a more comprehensive SC risk modelling.

As explained in the model definition section, in order to avoid non-linearity in revenue function, different price change values are defined as alternative scenarios and each scenario is solved separately instead of defining sales price as a decision variable. In a new study, a non-linear model also defining sales price as a decision variable may be defined and solved by non-linear solution algorithms.

In sensitivity analysis section of the study, sensitivity of the model objectives and model decisions against the changes in several coefficients is analyzed; however, the sensitivity of the model against the definitions of the some parameters such as one day replenishment coverage distance is not analyzed. This type of sensitivity analysis may also be subject to further studies.

Another limitation of the developed model is regarding the size and solution method of the model. Even though the model may be called quite big and complex since it was consisting of 282 binary variables and 6,446 variables. However, simplex method was good enough to find the optimal solution for the developed model. In case new SC nodes, links, and constraints added to the model, simplex method may not be enough to find the optimal solution. In that case, a heuristic method may be utilized to find the optimal solution.

As explained in the study, even though the demand is influenced by the SC decisions, the whole model is deterministic in its nature. The model may also be defined as stochastic model to explore how SC decisions change when the model parameters are defined as stochastic.

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APPENDICES

Appendix I. Various Features of Reviewed Articles / Models before 2009

The Study	Classification criteria						
	# of Periods	# of Commodities	Model Nature	Multistage vs. Single Stage	# of objective functions	Performance Measures	Solution Algorithm
Altiparmak et al. (2006)	Single	Single	Deterministic	Simple model with multistage procedure to find pareto optimal solution.	Multi-objective	Cost Minimization CSL Maximization Max.of Capacity Utilization	Genetic Algorithm
Amiri (2006)	Single	Single	Deterministic	Single	Single Objective	Cost Minimization	Lagrangean Relaxation – Heuristic Solution
Arntzen et al. (1995)	Single	Multiple	Deterministic	Single Stage with multiple modules	Multi-objective	Cost Minimization Cycle Time Minimization	Exact Solution (Math. Programming with specific algorithms to exclude some alternatives)
Bidhandi et al. (2009)	Single	Multiple	Deterministic	Single Stage: Benders Decomposition – Strategic and operational sub-models	Multi-objective	Cost Minimization Profit Maximization Service Level Maximization	Heuristic - Benders' Decomposition
Camm et. al. (1997)	Single	Single	Deterministic	Two stage: DC Location Problem – Product sourcing model	Singe Objective	Cost minimization	Heuristic Algorithm
Chen and Lee (2004)	Multiple	Multiple	Stochastic	Multiple	Multiple	Fair profit distribution Safe inventory levels Maximum CSL Robustness of decision	Fuzzy aggregation MINLP
Cohen and Lee (1987)	Single	Multiple	Deterministic	Single Stage	Single	Cost Minimization	Exact Solution
Cohen and Lee (1989)	Single	Single	Deterministic	Single Stage	Single	After Tax Profit Maximization	Exact Solution
Cohen and Lee (1988)	Single	Multiple	Stochastic	Multistage – Submodels to calculate the included random variables	Single	Cost Minimization	Exact Solution
Cohen and Moon (1990)	Single	Multiple	Deterministic	Single Stage	Single	Cost Minimization	Exact Solution
Cordeau et al. (2006)	Single	Multiple	Deterministic	Single Stage	Single	Cost Minimization	Heuristic Solution – Branch and Bound Benders' Decomposition
Ding et. al. (2006)	Generic	Generic	Stochastic	Multi stage: Optimization and simulation	Multi-objective	Generic	Genetic algorithm Simulation

The Study	Classification criteria # of Periods	# of Commodities	Model Nature	Multistage vs. Single Stage	# of objective functions	Performance Measures	Solution Algorithm
Guillen et. al.	Single	Single	Stochastic	Multi stage	Multi-objective	Net present value maximization Demand satisfaction maximization Financial risk minimization	Exact solution
Kabak and Ulengin (2011)	Single	Multiple	Stochastic	Multi stage	Single	Profit maximization	Fuzzy based possibilistic linear programming
Pokharel (2008)	Single	Single	Deterministic	Single Stage	Multi-objective	Cost minimization Service Level Maximization	Heuristic Solution - STEP
Pyke and Cohen (1993)	Single	Single	Stochastic	Multistage – Submodels to calculate the included random variables	Single	Cost minimization	Exact Solution
Rezapour and Farahani (2010)	Single	Single	Deterministic	Multistage: Integration of SC network optimization with competitive facility location.	Single	Profit maximization	Exact Solution
Rezapour et al. (2011)	Multiple	Single	Deterministic	Multistage: Integration of SC network optimization with competitive facility location then game theory.	Multiple Objective	Profit maximization Revenue Increase maximization	Exact Solution
Sabri and Beamon (2000)	Single	Single	Stochastic	Multistage: Strategic and operational level two sub-models.	Multi-objective	Cost Customer Service Level (CSL) Flexibility (Volume or Delivery)	Exact Solution and ε Constraint method
Talluri and Baker et. al. (2002)	Single	Single	Deterministic and Game Theory	Multistage: 3 phase starts with supplier selection	Single (SC optimization)	Cost Minimization	Exact Solution
Yimer and Demirli (2010)	Single	Multiple	Deterministic	Multistage: First Stage: Assembly and distribution schedule Second Stage: Manufacturing and procurement planning	Multi-objective	Cost Minimization Customer Satisfaction maximization	Exact Solution
Wikner et. al. (1991)	Single	Single	Stochastic	Single	Single	Demand amplification	Simulation

Appendix II. Various Features of Reviewed Articles / Models during last five years

No	Article	Number of Periods	Number of Commodities	SC Network Coverage	Decision Variables	Model Nature	Solution Algorithm	Performance Measures	Number of Objective Functions	SC Competition (Demand)	Competition within the chain	SC Risks	Green SC	Reverse Logistics	Real life Case	Globalization
1	Cruz et al.; 2011	Multi-period	Single Commodity	Supplier Manufacturer Retailer	Network traffic and the price at each echelon. Does not model 0-1 decisions.	Stochastic (Demand depends on the cost function)	Problem specific heuristic (Variational inequalities)	Profit max. Risk minimization Emission minimization	Multi objective	No competition (Demand is a function of the price)	Yes	Yes	No	No	No	No
2	Nagurney, 2010(a)	Single Period	Single Commodity	Supplier Manufacturer Distribution Centers Retailer	Network traffic and the price at each echelon. Does not model 0-1 decisions.	Stochastic (Demand depends on the cost function)	Problem specific heuristic (Variational inequalities)	Profit maximization	Single - Profit Maximization	Yes (Oligopolistic Competition)	Yes	No	No	No	No	No
3	Nagurney & Nagurney, 2012	Single Period	Single Commodity	Supplier Manufacturer DCs Retailer	Network link capacities Optimal product flows	Deterministic	Problem spcific heuristic (Variational inequalities)	Cost minimization	Single - Cost Minimization	No	No	No	No	Yes	Yes	No
4	Nagurney , 2010(b)	Single Period	Single Commodity	Manufacturer Distribution Centers Retailer	Network link capacities Optimal product flows	Deterministic	Problem specific heuristic (Variational inequalities)	Cost minimization	Single - Cost Minimization	No	No	No	No	No	No	No
5	Yamada et al., 2011	Single Period	Multi Commodity	Manufacturer Wholesaler Retailer Consumer Freight Carriers	Network traffic and the price at each echelon. Does not model 0-1 decisions. Freight carrier costs	Stochastic (Demand depends on the cost function)	Problem specific heuristic (Variational inequalities)	Profit maximization	Single - Profit Maximization	No competition (Demand is a function of the price)	Yes	No	No	No	No	No
6	Baghalian et. al., 2013	Single Period	Multi Commodity	Manufacturer Distribution Centers Retailers	Strategic facility location selections Optimal product flows within the network	Stochastic	Problem Specific Heuristic (Piecewise Linearization Method)	Profit maximization	Single - Profit Maximization	No	No	Yes	No	No	Yes	No

No	Article	Number of Periods	Number of Commodities	SC Network Coverage	Decision Variables	Model Nature	Solution Algorithm	Perfromance Measures	Number of Objective Functions	SC Competition (Demand)	Competition within the chain	SC Risks	Green SC	Reverse Logistics	Real life Case	Globalization
7	Badri et. al., 2013	Multi-period	Multi Commodity	Vendors Plants Warehouses Demand Zones	Supplier Selection Production facility and warehouse location selection Optimal product flow Capacity Expansion planning	Deterministic	Heuristic Solution (Lagrangian Relaxation)	Total Net Income Maximization	Single - Profit Maximization	No	No	No	No	No	No	No
8	Carle et.al., 2012	Multi-period	Multi Commodity	Vendors Plants Warehouses Demand Zones	Vendor Contracts Facility Location Selection Transportation Options Optimal Product Flow Inventory Decisions	Stochastic (Demand is determined by demand market policies)	Problem Specific Heuristic (Collaborative Agent Team)	Operating Profit Maximization	Single - Profit Maximization	No Competition (Demand is a function of marketing policy)	No	No	No	No	No	No
9	Nagurney, 2009	Single Period	Single Commodity	Manufacturers Distribution Centers Retailers	Optimal Product Flows Link Capacities	Deterministic	Problem specific heuristic (Variational inequalities)	Cost minimization	Single - Cost Minimization	No	Yes	No	No	No	No	No
10	Lundin, 2012	Multi-period	Single Commodity	Central Bank Depots Banks and Terminals Customers	Optimal Product Flows	Stochastic (Scenario Based)	Mathematical Model Exact Solution	Cost Minimization	Single - Cost Minimization	No	No	Yes	No	Yes	Yes	No
11	Kabak and Ulengin, 2011	Single Period	Multi Commodity	Raw and Semi-finished material suppliers Production resources Demand points	Outsourcing or internal production decision Optimal product flow Resource allocation Demand satisfaction level	Fuzzy based model	Problem specific heuristic	Profit maximization	Single - Profit Maximization	No	No	No	No	No	Yes	No

No	Article	Number of Periods	Number of Commodities	SC Network Coverage	Decision Variables	Model Nature	Solution Algorithm	Performance Measures	Number of Objective Functions	SC Competition (Demand)	Competition within the chain	SC Risks	Green SC	Reverse Logistics	Real life Case	Globalization
12	Longinidis and Georgiadis, 2011	Multi-period	Single Commodity	Plants Warehouse Distribution Centers Customer Zones	Warehouse and DC location selection Optimal Product Flow Production and inventory level decisions	Stochastic (Scenario Based)	Mathematical Model Exact Solution	Maximization of the expected net present value	Single - Profit Maximization	No	No	No	No	No	Yes	No
13	Zhang et. al., 2012	Single Period	Single Commodity	Dispersed manufacturing (3 stages) Market	Facility location selection Optimal product flow	Deterministic	Heuristic Solution (Branch - Bound Algorithm)	Cost Minimization Minimization of total weighted activity days	Multi objective	No	No	No	No	No	Yes	Yes
14	Kadadevaramath et. al., 2012	Single Period	Single Commodity	Vendors Plants Distribution Centers	Optimal Product Flow Procurement Scheduling Production scheduling Distribution scheduling	Deterministic	Heuristic Solution (Particle Swarm Optimization)	Cost Minimization	Single - Cost Minimization	No	No	No	No	No	No	No
15	Yu and Nagurney, 2013	Single Period	Single Commodity	Production Facility Processing Facilities Storage Facilities DCs Disposal of the food products	Network traffic and the price at each echelon. Does not model 0-1 decisions.	Stochastic (Demand depends on the competition on the market)	Problem specific heuristic (Euler method - variational inequalities)	Profit maximization	Single - Profit Maximization	Yes (Oligopolistic Competition)	Yes	Yes (Food Perishability)	No	Yes	Yes	No
16	Yang et. al., 2009	Single Period	Single Commodity	Supplier Manufacturer Retailer Consumers Recovery Centers	Network traffic and the price at each echelon. Does not model 0-1 decisions.	Stochastic (Demand depends on the competition on the market)	Problem Specific Heuristic (extragradient method with constant step length - variational inequalities)	Profit maximization	Single - Profit Maximization	No competition (Demand is a function of the price at the market and price at the other markets)	Yes	No	No	Yes	No	No

No	Article	Number of Periods	Number of Commodities	SC Network Coverage	Decision Variables	Model Nature	Solution Algorithm	Performance Measures	Number of Objective Functions	SC Competition (Demand)	Competition within the chain	SC Risks	Green SC	Reverse Logistics	Real life Case	Globalization
17	Melo et. Al, 2012	Multi-period	Multi Commodity	Suppliers Plants Warehouses	Facility Location Selection Optimal Flow Inventory decisions	Deterministic	Heuristic Solution (Tabu search heuristic)	Cost Minimization	Single - Cost Minimization	No	No	No	No	No	No	No
18	Corsana and Montagna, 2011	Single Period	Multi Commodity	Raw material site Plants Warehouses Customer Zones	Plant (Facility) design Facility Location Selection Optimal Product Flow	Deterministic	Mathematical Model Exact Solution	Cost Minimization	Single - Cost Minimization	No	No	No	No	No	No	No
19	Cruz, 2009	Single Period	Single Commodity	Manufacturer Retailer Demand Markets	Network traffic and the price at each echelon. Does not model 0-1 decisions. Via Physical or internet links	Stochastic (Demand depends on the cost function)	Problem Spcfc Heuristic (Variational inequalities - modified projection method of Korpelevich)	Profit maximization Risk minimization Emission minimization	Multi objective	No competition (Demand is a function of the price)	Yes	Yes	Yes	No	No	No
20	Chen, 2010	Single Period	Multi Commodity	Component Plants Assembly Plants DCs	Production or substitution decision Optimal product flow	Deterministic	Heuristic Solution (Genetic algorithm)	Maximization of Sales Profit	Single - Profit Maximization	No	Yes	No	No	No	No	No
21	Altiparmak et. al., 2009	Single Period	Multi Commodity	Supplier Plants DCs Customers	Facility Location Selection Optimal Product Flow	Deterministic	Heuristic Solution (Genetic algorithm)	Cost Minimization	Single - Cost Minimization	No	No	No	No	No	No	No
22	Cardoso et. al., 2013	Multi-period	Multi Commodity	Production assembly Storage Facility DCs Collection Facilities Sorting Facilities Remanufacturing Plant Disposal Cntr	Facility Location Decisions Facility Capacity Decisions Optimal product flow Definition of the processes to install at each node Inventory level decisions	Stochastic (Scenario Based)	Mathematical Model Exact Solution	Maximization of the expected net present value	Single - Profit Maximization	No	No	No	No	Yes	No	No

No	Article	Number of Periods	Number of Commodities	SC Network Coverage	Decision Variables	Model Nature	Solution Algorithm	Performance Measures	Number of Objective Functions	SC Competition (Demand)	Competition within the chain	SC Risks	Green SC	Reverse Logistics	Real life Case	Globalization
23	Shankar et. al. 2013	Single Period	Single Commodity	Supplier Plants Distribution Centers Customer Zones	Facility Location Selection Optimal Product Flow	Deterministic	Heuristic Solution (Multi Objective Hybrid Particle Swarm Optimization)	Cost minimization Maximization of customer demands met	Multi objective	No	No	No	No	No	No	No
24	Bpjarski et. al. 2009	Multi-period	Multi Commodity	Suppliers SC Facilities (either processing or storing) Market locations	SC Facility location decisions Optimal product flows Capacities in each period Manufacturing and distribution assignments The amount of final products to be sold The processing technology selection	Deterministic	Mathematical Model Exact Solution	Damage categories impact overall impact factor net present value	Multi objective	No	No	No	Yes	No	Yes	No
25	Nagurney and Yu, 2012	Single Period	Single Commodity	Production Facility Storage Facility Distribution Center	Network traffic and the price at each echelon. Does not model 0-1 decisions.	Stochastic (Demand depends on the cost function)	Problem specific heuristic (Euler method - variational inequalities)	Profit maximization Total emission minimization	Multi objective	Yes (Oligopolistic Competition)	No	No	Yes	No	No	No
26	Salema et. al., 2010	Multi-period	Multi Commodity	Suppliers Production Facility Storage and DCs Recovery Centers	Facility Location decisions Production rate decisions Optimal product flow amounts	Deterministic	Mathematical Model Exact Solution	Cost minimization	Single - Cost Minimization	No	No	No	No	Yes	Yes	No
27	Xu et. al., 2009	Single Period	Single Commodity	Manufactories Finishing facilities Warehouses	Facility Location Selection Optimal Product Flow	Fuzzy based model	Heuristic Solution (spanning tree genetic algorithm)	Cost minimization	Single - Cost Minimization	No	No	No	No	No	No	No

No	Article	Number of Periods	Number of Commodities	SC Network Coverage	Decision Variables	Model Nature	Solution Algorithm	Performance Measures	Number of Objective Functions	SC Competition (Demand)	Competition within the chain	SC Risks	Green SC	Reverse Logistics	Real life Case	Globalization
28	Zeballos et. al., 2012	Multi-period	Multi Commodity	Suppliers Production Facility Storage and DCs Recovery Centers	Facility Location Selection Optimal Product Flow	Stochastic (return quality and quantity is not known - demand is deterministic)	Mathematical Model Exact Solution	Profit maximization	Single - Profit Maximization	No	No	No	No	Yes	Yes	No
29	Costantino et. al., 2012	Single Period	Single Commodity	Suppliers Manufacturers DCs Retailers Final customers	Supplier Selection Optimal Product Flow	Deterministic	Mathematical Model Exact Solution	Cost minimization Product Quality Transportation time	Multi objective	No	No	No	No	No	Yes	No
30	Bidhandi et. al., 2009	Single Period	Multi Commodity	Suppliers Manufacturers Warehouses Final customers	Facility Location Selection Optimal Product Flow	Deterministic	Heuristic Solution (Bender's Decomposition)	Cost minimization	Single - Cost Minimization	No	No	No	No	No	No	No
31	Masoumi et. al., 2012	Single Period	Single Commodity	Production Facility Shipment Center Storage Center DC Disposal Center	Network traffic and the price at each echelon. Does not model 0-1 decisions.	Stochastic (Demand depends on the competition on the market)	Problem specific heuristic (Euler method - variational inequalities)	Profit maximization	Single - Profit Maximization	Yes (Oligopolistic Competition)	No	Yes (Perishability)	No	No	No	No
32	Martinez and Zhang, 2011	Single Period	Multi Commodity	Production Facility Customers	Outsourcing or production decision Vendor Selection	Deterministic	Heuristic Solution (Ant colony optimization)	Cost minimization Lead time minimization	Multi objective	No	No	No	No	No	No	No
33	Bassett and Gardner, 2010	Multi-period	Multi Commodity	Suppliers Factories (Formulation) Factories (Packaging) Customers	Selection of facilities Capacity Expansions Optimal Flow Production scheduling Shipping schedules	Deterministic	Mathematical Model Exact Solution	Profit maximization	Single - Profit Maximization	No	No	Yes	No	No	Yes	Yes

No	Article	Number of Periods	Number of Commodities	SC Network Coverage	Decision Variables	Model Nature	Solution Algorithm	Performance Measures	Number of Objective Functions	SC Competition (Demand)	Competition within the chain	SC Risks	Green SC	Reverse Logistics	Real life Case	Globalization
34	Chaabane et. Al, 2012	Multi-period	Multi Commodity	Suppliers Manufacturers Distribution Centers Customers Recycling Centers	Facility Location Selection Optimal Product Flows Inventory decisions	Deterministic	Mathematical Model Exact Solution	Cost minimization Carbon emission minimization	Multi objective	No	No	No	Yes	Yes	No	No
35	Prakash et. al., 2012	Single Period	Single Commodity	Supplier Central Warehouse Retailers	Supplier Selection Optimal product flow Inventory policy selection	Deterministic	Heuristic Solution (Knowledge Based Genetic Algorithm)	Minimization of the total average cost per fill demand Maximization of the demand fill rate	Multi objective	No	No	No	No	No	Yes	No
36	Costa et. al., 2010	Single Period	Single Commodity	Suppliers Plants Distribution Centers Customers	Facility Location Selection Optimal Product Flow	Deterministic	Heuristic Solution (Genetic algorithm)	Cost minimization	Single - Cost Minimization	No	No	No	No	No	No	No
37	Correia et. al., 2013	Multi-period	Multi Commodity	Central Warehouse Regional Warehouse Customer zones	Facility Location Decision Capacity decisions Optimal Product Flows	Deterministic	Mathematical Model Exact Solution	Cost minimization or Profit maximization	Single - Cost Minimization Single - Profit Maximization	No	No	No	No	No	No	No
38	Wang, 2009	Single Period	Single Commodity	Supplier Manufacturer Distribution Centers Customers	Supplier Selection Facility Location Selection Optimal Product Flow Distribution Scheduling	Deterministic	Heuristic Solution (Ant colony optimization)	Cost minimization	Single - Cost Minimization	No	No	Yes (Yield rate)	No	No	No	No
39	Zamarripa et. al., 2012	Multi-period	Multi Commodity	Production Distribution Centers Final Customer	Production level decisions Inventory decisions Optimal product flow	Stochastic (Demand depends on the cost function)	Mathematical Model Exact Solution	Cost minimization Spend of the buyers at each SC	Multi objective	Yes (Oligopolistic Competition)	No	No	No	No	No	No

No	Article	Number of Periods	Number of Commodities	SC Network Coverage	Decision Variables	Model Nature	Solution Algorithm	Performance Measures	Number of Objective Functions	SC Competition (Demand)	Competition within the chain	SC Risks	Green SC	Reverse Logistics	Real life Case	Globalization
40	Copado-Mendez et. al., 2013	Multi-period	Multi Commodity	Production Plants Storage Facilities Final Markets	Facility Location Selection Capacity expansion decision Production rate Inventory level Optimal Product Flow	Stochastic (scenario based)	Problem Specific Heuristic (Large Neighborhood Search with Branch - Cut techniques)	Cost minimization	Single - Cost Minimization	No	No	No	No	No	Yes	No
41	Amaro and Barbosa-Póvoa, 2009	Multi-period	Multi Commodity	Suppliers Industrial facilities Transportation providers, DCs Customers Disposal sites	Facility Location Selection Optimal Product Flow	Stochastic (scenario based - Demand and price elasticity)	Heuristic Solution (Branch - Bound Algorithm)	Maximization of Actualized SC Profit	Single - Profit Maximization	No competition (Demand is a function of the price)	Yes	No	No	Yes	Yes	No
42	Nepal et. al., 2012	Single Period	Single Commodity	Suppliers Assembly Lines Demand Points	Product design Supplier selection Facility Location Selection Optimal Product Flow	Fuzzy based model	Heuristic Solution (Genetic algorithm)	Cost minimization Max. of total supply chain compatibility index	Multi objective	No	No	No	No	No	Yes	No
43	Sadjady and Davoudpour, 2012	Single Period	Multi Commodity	Plants Warehouses Customers	Facility Location Decision Manufacturing Plant Capacity Decision Selecting transportation modes Optimal Product Flow	Deterministic	Heuristic Solution (Lagrangian Relaxation Method)	Cost minimization	Single - Cost Minimization	No	No	No	No	No	No	No
44	Tiwari et. al., 2010	Single Period	Single Commodity	Supplier Manufacturer Warehouses DCs Customers	Facility Location decisions Optimal Product Flow Shipment Options	Stochastic	Problem specific heuristic	Cost minimization	Single - Cost Minimization	No	No	No	No	No	No	No

No	Article	Number of Periods	Number of Commodities	SC Network Coverage	Decision Variables	Model Nature	Solution Algorithm	Performance Measures	Number of Objective Functions	SC Competition (Demand)	Competition within the chain	SC Risks	Green SC	Reverse Logistics	Real life Case	Globalization
45	Schütz et. al., 2009	Multi-period	Multi Commodity	Raw Material Suppliers Work-in-Processes Distribution Centers Customer Locations	Facility Location Decision Capacity of production facilities Inventory decisions Optimal flow Unsatisfied demand rate	Stochastic	Problem specific heuristic	Cost minimization	Single - Cost Minimization	No	No	No	No	No	Yes	No
46	Hsu and Li, 2011	Multi-period	Single Commodity	Suppliers Plants Customer locations	Facility location decision Capacity and production amounts at plants Optimal flows	Stochastic (scenario based)	Heuristic Solution (Simulated Annealing)	Average per-unit product cost	Single - Cost Minimization	No	No	Yes (Demand fluctuation)	No	No	Yes	No
47	Kim et. al., 2011	Multi-period	Multi Commodity	Biomass sites Conversion I Plants Conversion II Plants Customer Markets	Facility location decisions Capacity of the processing facilities Optimal Product flows	Stochastic	Hybrid Solution (Mathematical formulation and simulation)	Maximization of the expected profit over the different scenarios	Single - Profit Maximization	No	No	Yes (Simulation and sensitivity)	No	No	Yes	No
48	Akgul et. al., 2012	Multi-period	Multi Commodity	Biomass cultivation nodes Biofuel transportation centers Demand points	Biomass cultivation rate Location and capacities of production facilities Optimal traffic flow Transportation mode selection	Deterministic	Mathematical Model Exact Solution	Cost minimization Minimization of environmental effect	Multi objective	No	No	No	Yes	No	Yes	No
49	Pan and Nagi, 2010	Single Period	Single Commodity	5 echelon SC (roles are not specified)	Vendor Selection SC location selection Optimal flow Production planning Inventory decisions	Stochastic (Scenario based)	Heuristic Solution (k-shortest path based)	Cost minimization SC Robustness	Multi objective	No	No	Yes (Robustness)	No	No	No	No

No	Article	Number of Periods	Number of Commodities	SC Network Coverage	Decision Variables	Model Nature	Solution Algorithm	Performance Measures	Number of Objective Functions	SC Competition (Demand)	Competition within the chain	SC Risks	Green SC	Reverse Logistics	Real life Case	Globalization
50	Pinto-Varela et. al., 2011	Single Period	Multi Commodity	Suppliers Plants Warehouses Distribution Centers Markets Resource Task Network	Facility Location Selections Optimal flow Resource allocation Technology selection Sold products Process selection Capacity selection	Hybrid (Deterministic and fuzzy linear to solve bi-objectivity)	Hybrid solution (Exact solution and Fuzzy linearization to solve bi-objectivity)	Maximization of total profit Minimization of env'l impact	Multi objective	No	No	No	Yes	No	No	No
51	Nikolopoulou and Lerapetritou, 2012	Single Period	Multi Commodity	Suppliers Plants Markets	Supplier selection Facility location selection Optimal flow Production scheduling Distribution scheduling	Deterministic	Simulation	Cost minimization	Single - Cost Minimization	No	No	No	No	No	No	No
52	Yoo et. al., 2010	Single Period	Multi Commodity	Suppliers Plants Distribution Centers	Supplier Selection Optimal Flow Location of DCs Inventory Policy	Stochastic	Hybrid (Simulation and Heuristic)	Cost minimization	Single - Cost Minimization	No	No	No	No	No	No	No
53	Olivares-Benitez et. al., 2013	Single Period	Single Commodity	Plants Distribution Centers Customers	DC Selection Transportation mode selection Optimal product flow	Deterministic	Problem specific heuristic	Cost minimization Minimization of total time	Multi objective	No	No	No	No	No	No	No
54	Li et. al., 2009	Multi-period	Multi Commodity	Suppliers Plants Distribution Centers	Capacity allocation at plants Capacity allocation at Distribution Centers Optimal product flow Inventory amount Unsatisfied demand rate	Deterministic	Heuristic Solution (Lagrangian Relaxation)	Maximization of overall profit	Single - Profit Maximization	No	No	Yes (Sensitivity analysis)	No	No	No	No

No	Article	Number of Periods	Number of Commodities	SC Network Coverage	Decision Variables	Model Nature	Solution Algorithm	Performance Measures	Number of Objective Functions	SC Competition (Demand)	Competition within the chain	SC Risks	Green SC	Reverse Logistics	Real life Case	Globalization
55	Hammami et. Al, 2009	Multi-period	Multi Commodity	Supplier Manufacturer Distribution Centers Customers	Facility location selection Supplier selection Technology selection Capacity decision Optimal cash flow Transfer pricing	Deterministic	Heuristic Solution (Branch - Cut Algorithm)	Maximization of global after tax profit	Single - Profit Maximization	No	No	No	No	No	Yes	Yes
56	Kumar and Tiwari, 2013	Single Period	Multi Commodity	Plants DCs Retailers Demand Locations	Facility location selection Capacity decisions Optimal product flow	Stochastic	Heuristic Solution (Lagrangian Relaxation)	Cost minimization	Single - Cost Minimization	No	Integration effect	Yes (Risk pooling)	No	No	No	No
57	Susarla and Kamiri, 2012	Multi-period	Multi Commodity	Procurement Nodes Production Facility DC	Production planning Inventory planning	Deterministic	Problem specific heuristic	Maximization of total profit after tax	Single - Profit Maximization	No	No	No	No	Yes	Yes	Yes
58	Meng et. al., 2009	Single Period	Single Commodity	Manufacturer Retailer Demand Markets	Network traffic and the price at each echelon. Does not model 0-1 decisions.	Stochastic (Demand depends on the cost function)	Problem specific heuristic (Variational inequalities)	Maximization of the profit	Single - Profit Maximization	No competition (Demand is a function of the price)	Yes	No	No	No	No	No
59	Osman and Demirli, 2010	Multi-period	Multi Commodity	T2 Suppliers (Components) T1 Suppliers (Machining) Production Facility	Supplier selection Distribution center location decision Optimal product flow Inventory Model	Deterministic	Problem specific Heuristic (Bender's Decomposition)	Cost minimization Max.of preferred suppliers Max. of on time delivery	Multi objective	No	No	No	No	No	Yes	No
60	El-sayed et. al., 2010	Multi-period	Single Commodity	Suppliers Production Facilities Distribution Centers Disassembly Centers Redistribution Center	Facility location decisions Production at each location Optimal product flow Inventory amounts Demand satisfaction level	Stochastic	Mathematical Model Exact Solution	Maximization of total expected profit	Single - Profit Maximization	No	No	Yes (Sensitivity analysis)	No	Yes	No	No

No	Article	Number of Periods	Number of Commodities	SC Network Coverage	Decision Variables	Model Nature	Solution Algorithm	Performance Measures	Number of Objective Functions	SC Competition (Demand)	Competition within the chain	SC Risks	Green SC	Reverse Logistics	Real life Case	Globalization
61	Kostin et. al., 2011	Multi-period	Multi Commodity	Production Facility Storage Facility Demand Market	Number, capacity and the location of production plants and warehouses Transportation modes Optimal flows	Deterministic	Heuristic Solution (Branch and Cut)	Maximization of Net Present Value	Single - Profit Maximization	No	No	Yes (Sensitivity to price changes)	No	Yes (Disposal costs)	Yes	No
62	Wang and Hsu, 2010	Single Period	Single Commodity	Suppliers Manufacturers DCs Customers Recycling Centers	Facility location decisions Optimal product flow	Deterministic	Heuristic Solution (spanning tree genetic algorithm)	Cost minimization	Single - Cost Minimization	No	No	No	Yes	Yes	No	No
63	Huang et. al., 2010	Multi-period	Multi Commodity	Feedstock fields Refineries City gates	Refinery capacity and locations Production decisions Optimal flow Demand satisfaction level	Deterministic	Mathematical Model Exact Solution	Cost minimization	Single - Cost Minimization	No	No	Yes (Sensitivity analysis)	No	Yes (Disposal costs)	Yes	No
64	Andersen et. al., 2012	Multi-period	Multi Commodity	Crop fields Storage Plants Distribution Centers Customers	Farm planning Optimal product flow Facility location selection Demand satisfaction level	Deterministic	Mathematical Model Exact Solution	Maximization of Net Present Value	Single - Profit Maximization	No	No	Yes (Sensitivity to demand changes)	No	Yes (Disposal costs)	Yes	Yes
65	Pimentel et. al., 2013	Multi-period	Multi Commodity	Production Facilities Customers	Facility location selection Capacity selection Optimal product flow Demand satisfaction rate	Stochastic (Scenario based)	Heuristic Solution (Lagrangian Relaxation)	Cost minimization	Single - Cost Minimization	No	No	No	No	No	No	No
66	Wang et. al., 2011	Single Period	Single Commodity	Plants Marketplace	Facility Location Selection Optimal flow	Stochastic	Heuristic Solution (Greedy)	Profit maximization	Single - Profit Max.	No	No	No	No	No	No	No

No	Article	Number of Periods	Number of Commodities	SC Network Coverage	Decision Variables	Model Nature	Solution Algorithm	Performance Measures	Number of Objective Functions	SC Competition (Demand)	Competition within the chain	SC Risks	Green SC	Reverse Logistics	Real life Case	Globalization
67	Baumgarten et. al., 2012	Single Period	Multi Commodity	Plants Tank farms (Distribution Centers) Customers	Location and the capacity of tank farms Optimal product flow Transport frequency selection	Deterministic	Heuristic Solution (Branch-and-bound)	Cost minimization	Single - Cost Minimization	No	No	No	No	No	Yes	No
68	Bashiri and Tabrizi, 2010	Single Period	Single Commodity	Distribution Centers Retailer Customer points	Distribution Center Location Decisions Optimal Product Flow	Stochastic	Problem Specific Heuristic (Particle Swarm Optimization)	Cost minimization	Single - Cost Minimization	No	No	No	No	No	No	No
69	Bogataj et. al., 2011	Single Period	Multi Commodity	Production Facility Distribution Center Reverse Logistics	Facility Location Selection Capacity Selection Optimal Product Flow	Deterministic	Problem specific heuristic	NPV maximization	Single - Profit Maximization	No	No	Yes (Time delays)	Yes	Yes	No	No
70	Thanh et. al., 2012	Multi-period	Multi Commodity	Suppliers Plants Distribution Centers Retailer or Final Customers	Supplier selection Facility location selections Capacity expansion decision Optimal product flow	Deterministic	Problem specific heuristic	Cost minimization	Single - Cost Minimization	No	No	No	No	No	No	No
71	Lee and Dong, 2009	Multi-period	Multi Commodity	Plants Depots Customers	Facility Location Decisions Capacity decisions Optimal product flow	Stochastic	Problem specific heuristic (Sample Average Approximation with Simulated annealing algorithm)	Cost minimization	Single - Cost Minimization	No	No	No	Yes	Yes	No	No

Appendix III. Model Company Data

Table 1. Suppliers of each product type and supply rates

Supplier No	CHINO	ÇORAP	DENIM	GÖMLEK	KANVAS	MKP	ÖRME	SWEAT SHIRT	TRIKO	TSHIRT	Total no of Sales
1	4,82%		31,33%		4,51%						13.344
2	49,10%				17,60%						71.729
3	10,85%		68,67%								24.248
4	22,43%				11,70%						34.753
5	12,79%				16,19%						24.974
6		100,00%									155.838
7				2,69%							14.111
8 (P)				32,46%	10,71%						176.351
9				17,51%							91.997
10				3,24%							17.039
11				24,04%							126.327
12				3,32%							17.461
13				6,80%							35.730
14				9,94%							52.225
15					39,29%						21.294
16						13,60%					20.745
17						8,69%					13.260
18						77,71%					118.530
19							87,49%	32,57%		14,75%	221.666
20							8,58%	10,07%			50.381
21							3,93%	12,25%		33,63%	85.452
22								2,33%		16,65%	24.583
23								19,44%			84.546
24								4,96%		5,28%	26.159
25								18,37%		29,69%	105.639
26									19,54%		118.454
27									2,29%		13.869
28									2,04%		12.390
29									59,03%		357.883
30									5,64%		34.206
31									2,59%		15.729
32									8,87%		53.788
	126.656	**155.838**	**15.299**	**525.436**	**54.192**	**152.535**	**76.876**	**434.841**	**606.319**	**86.709**	**2.234.701**

Table 2. Retail Outlet Locations and Seasonal Demand

City No	City	No of Outlets	Total Sales (%)	Demand for Each Product Type - 2012 Fall and Winter									
				CHINO	ÇORAP	DENIM	GÖMLEK	KANVAS	MKP	ÖRME	SWEAT SHIRT	TRIKO	TSHIRT
1	Adana	5	1,82%	2.305	2.322	271	10.561	1.149	1.968	1.468	8.305	11.702	1.656
2	Afyon	2	0,92%	1.140	1.449	92	2.364	867	1.830	846	4.392	2.425	815
3	Ankara	19	6,74%	8.258	10.052	1.072	36.150	3.788	8.939	5.320	26.003	46.202	6.174
4	Antalya	5	2,26%	2.837	3.615	329	11.665	1.382	3.341	1.538	11.654	12.793	1.812
5	Aydın	4	1,69%	1.988	2.509	236	8.092	818	2.349	1.407	7.436	10.246	1.431
6	Balıkesir	1	0,25%	1.634	452	18	1.051	119	168	77	174	667	52
7	Batman	2	0,45%	557	1.106	67	2.680	222	625	338	913	3.699	312
8	Bolu	3	0,68%	912	1.091	101	3.626	379	1.037	400	2.609	4.911	590
9	Bursa	13	5,96%	7.625	9.054	874	31.579	3.252	9.472	4.659	25.090	34.014	5.541
10	Çorum	1	0,39%	494	468	47	2.154	217	503	254	1.826	3.699	347
11	Denizli	2	0,83%	1.013	1.371	139	4.624	477	1.388	677	2.913	4.365	668
12	Diyarbakır	4	1,35%	1.761	2.166	203	6.988	602	2.029	1.084	6.131	7.822	1.309
13	Edirne	3	1,42%	2.039	2.182	203	7.934	656	2.837	1.107	5.131	7.822	1.171
14	Erzurum	1	0,37%	443	514	47	2.049	217	503	254	1.783	2.001	408
15	Eskişehir	2	0,94%	1.267	1.558	153	5.202	537	1.525	769	2.913	5.336	789
16	Gaziantep	4	5,55%	7.105	9.054	852	29.477	3.230	9.152	4.228	22.655	31.771	4.344
17	Giresun	1	0,28%	355	312	34	631	184	336	169	1.478	2.607	338
18	Hatay	4	1,35%	1.659	1.714	170	9.037	764	2.059	853	6.566	8.549	1.249
19	Isparta	1	0,20%	266	203	26	578	135	183	184	957	0	442
20	İçel	6	2,01%	2.533	2.883	329	10.509	1.084	3.386	1.222	9.001	12.975	1.804
21	İstanbul	77	42,05%	52.486	67.213	6.459	215.429	22.571	63.882	33.064	182.503	255.988	36.418
22	İzmir	11	3,80%	4.737	5.704	519	17.497	2.086	5.796	2.852	17.915	26.921	3.399
23	K.Maraş	1	0,56%	646	655	103	5.254	320	641	392	1.739	3.092	486
24	Kayseri	4	2,01%	2.685	3.288	347	10.509	1.095	2.852	1.707	6.392	12.611	1.682
25	Kırklareli	1	0,53%	684	701	63	2.522	298	839	384	2.392	3.941	512
26	Kocaeli	3	1,93%	2.444	2.945	301	10.509	1.084	3.768	1.407	9.219	7.336	1.647
27	Konya	3	1,29%	1.824	2.182	216	8.249	710	1.846	838	6.175	6.063	910
28	Malatya	2	1,16%	1.393	1.543	170	8.092	602	1.785	853	5.175	6.063	1.075
29	Mardin	1	0,49%	633	670	107	2.732	265	671	307	2.653	2.425	390
30	Muğla	1	0,54%	760	1.044	84	3.205	330	778	223	2.826	2.547	424
31	Ordu	1	0,39%	355	468	50	2.102	125	534	361	1.827	3.699	399
32	Osmaniye	1	0,31%	342	436	60	2.102	222	473	269	1.435	1.334	156
33	Sakarya	3	1,32%	1.647	1.730	216	6.200	721	1.785	899	6.131	8.731	1.430
34	Samsun	1	1,56%	2.026	2.415	246	8.775	639	2.456	1.292	7.436	8.549	1.353
35	Sivas	1	0,56%	659	779	84	3.153	271	930	392	2.653	3.274	564
36	Şanlıurfa	2	0,49%	557	779	122	3.888	271	793	338	2.913	0	251
37	Tekirdağ	7	2,49%	3.116	3.756	384	13.399	1.214	3.829	2.160	11.350	16.189	1.873
38	Trabzon	5	2,34%	2.926	4.831	369	12.137	1.100	3.829	1.684	11.350	14.855	1.318
39	Zonguldak	1	0,71%	545	624	136	2.731	189	1.418	600	4.827	9.095	1.170
	Total Sales		100 %	126.656	155.838	15.299	525.436	54.192	152.535	76.876	434.841	606.319	86.709

Table 3. Inbound transportation costs for each product

Spplr No	Lokasyon	Chino			Çorap			Denim			Gömlek			Kanvas			MKP			Örme			SweatT Shirt			Triko			T-Shirt		
		İST	ANK	İZM	İST	ANK	İZM	İST	ANK	İZM	İST	ANK	İZM	İST	ANK	İZM	İST	ANK	İZM	İST	ANK	İZM	İST	ANK	İZM	İST	ANK	İZM	İST	ANK	İZM
1	Güngören	0,20	0,60	0,70				0,20	0,60	0,70				0,20	0,60	0,70															
2	Denizli	0,70	0,40	0,35										0,50	0,40	0,40															
3	Güneşli	0,20	0,65	0,70				0,20	0,60	0,70																					
4	Güneşli	0,20	0,65	0,70										0,20	0,60	0,70															
5	Başakşehir	0,20	0,65	0,70										0,20	0,60	0,70															
6	B.paşa				0,05	0,12	0,12																								
7	İstanbul										0,15	0,45	0,50																		
8	B.Çekmece										0,10	0,30	0,30	0,10	0,50	0,60															
9	İstanbul										0,15	0,45	0,50																		
10	Kağıthane										0,15	0,45	0,50																		
11	İstanbul										0,12	0,42	0,45																		
12	İstanbul										0,15	0,45	0,50																		
13	İstanbul										0,15	0,45	0,50																		
14	İstanbul										0,15	0,45	0,50																		
15	İstanbul													0,20	0,60	0,70															
16	İstanbul																0,60	1,20	1,40												
17	Kadıköy																0,60	1,20	1,40												
18	China																4.00	4,40	4.00												
19	İstanbul																			0,15	0,45	0,50	0,15	0,40	0,45				0,15	0,40	0,45
20	Bursa																			0,30	0,30	0,35	0,25	0,35	0,35						
21	Yalova																			0,25	0,40	0,45	0,25	0,35	0,35				0,25	0,35	0,35
22	Bağcılar																						0,15	0,40	0,45				0,15	0,40	0,45
23	GOPaşa																						0,15	0,40	0,45						
24	İstanbul																						0,15	0,40	0,45				0,15	0,40	0,45
25	İstanbul																						0,15	0,40	0,45				0,15	0,40	0,45
26	G.Gören																									0,20	0,60	0,70			
27	Z.Burnu																									0,20	0,60	0,70			
28	Sakarya																									0,30	0,50	0,55			
29	İstanbul																									0,20	0,60	0,70			
30	İkitelli																									0,20	0,60	0,70			
31	S.Beyli																									0,20	0,60	0,70			
32	Z.Burnu																									0,20	0,60	0,70			

Table 4. Outbound Transportation rates per product types

City	# of Outlets	CHINO			ÇORAP			DENIM			GÖMLEK			KANVAS			MKP			ÖRME			SWEAT SHIRT			TRIKO			TSHIRT		
		IST	ANK	IZM	IST	ANK	IZM	IST	ANK	IZM	IST	ANK	IZM	IST	ANK	IZM	IST	ANK	IZM	IST	ANK	IZM	IST	ANK	IZM	IST	ANK	IZM	IST	ANK	IZM
Adana	5	1,20	1,00	1,10	0,10	0,08	0,08	1,20	1,00	1,10	0,60	0,50	0,55	1,20	1,00	1,10	1,80	1,50	1,60	1,40	1,00	1,20	0,60	0,50	0,55	1,40	1,00	1,20	0,60	0,50	0,55
Afyon	2	1,00	0,85	0,60	0,12	0,10	0,10	1,00	0,85	0,60	0,50	0,43	0,30	1,00	0,85	0,60	1,50	1,30	1,00	1,00	0,85	0,60	0,50	0,43	0,30	1,00	0,85	0,60	0,50	0,43	0,30
Ankara	19	0,50	0,10	0,60	0,06	0,02	0,08	0,50	0,10	0,60	0,25	0,05	0,30	0,50	0,10	0,60	0,75	0,50	1,00	0,60	0,25	0,60	0,25	0,05	0,30	0,60	0,25	0,60	0,25	0,05	0,30
Antalya	5	1,10	0,90	0,80	0,10	0,08	0,06	1,10	0,90	0,80	0,55	0,45	0,40	1,10	0,90	0,80	1,50	1,30	1,20	1,10	0,90	0,80	0,55	0,45	0,40	1,10	0,90	0,80	0,55	0,45	0,40
Aydın	4	1,20	1,00	0,40	0,10	0,10	0,02	1,20	1,00	0,40	0,60	0,50	0,20	1,20	1,00	0,40	1,80	1,50	0,60	1,20	1,00	0,40	0,60	0,50	0,20	1,20	1,00	0,40	0,60	0,50	0,20
Balıkesir	1	0,80	0,80	0,40	0,06	0,08	0,06	0,80	0,80	0,40	0,40	0,40	0,20	0,80	0,80	0,40	1,20	1,20	0,60	0,80	0,80	0,40	0,40	0,40	0,20	0,80	0,80	0,40	0,40	0,40	0,20
Batman	2	1,60	1,40	1,70	0,18	0,12	0,18	1,60	1,40	1,70	0,80	0,70	0,85	1,60	1,40	1,70	2,20	2,00	2,40	1,80	1,60	2,00	0,80	0,70	0,85	1,80	1,60	2,00	0,80	0,70	0,85
Bolu	3	0,50	0,40	1,10	0,08	0,08	0,12	0,50	0,40	1,10	0,25	0,20	0,55	0,50	0,40	1,10	0,75	0,60	1,50	0,50	0,40	1,10	0,25	0,20	0,55	0,50	0,40	1,10	0,25	0,20	0,55
Bursa	13	0,40	0,60	0,60	0,04	0,06	0,08	0,40	0,60	0,60	0,20	0,30	0,30	0,40	0,60	0,60	0,60	0,90	0,90	0,40	0,60	0,60	0,20	0,30	0,30	0,40	0,60	0,60	0,20	0,30	0,30
Çorum	1	1,30	0,80	1,50	0,08	0,03	0,10	1,30	0,80	1,50	0,65	0,40	0,75	1,30	0,80	1,50	1,95	1,20	2,25	1,30	0,80	1,50	0,65	0,40	0,75	1,30	0,80	1,50	0,65	0,40	0,75
Denizli	2	1,10	1,00	0,60	0,12	0,10	0,10	1,10	1,00	0,60	0,55	0,50	0,30	1,10	1,00	0,60	1,65	1,50	0,90	1,10	1,00	0,60	0,55	0,50	0,30	1,10	1,00	0,60	0,55	0,50	0,30
Diyarbakır	4	1,40	1,00	1,60	0,18	0,12	0,18	1,40	1,00	1,60	0,70	0,50	0,80	1,40	1,00	1,60	2,10	1,50	2,40	1,80	1,60	2,00	0,70	0,50	0,80	1,80	1,60	2,00	0,70	0,50	0,80
Edirne	3	0,60	1,40	1,40	0,04	0,08	0,10	0,60	1,40	1,40	0,30	0,70	0,70	0,60	1,40	1,40	0,90	2,00	2,00	0,80	1,40	1,40	0,30	0,70	0,70	0,80	1,40	1,40	0,30	0,70	0,70
Erzurum	1	1,80	1,40	2,00	0,18	0,12	0,18	1,80	1,40	2,00	0,90	0,70	1,00	1,80	1,40	2,00	2,60	2,20	3,00	1,80	1,40	2,00	0,90	0,70	1,00	1,80	1,40	2,00	0,90	0,70	1,00
Eskişehir	2	0,70	0,50	0,80	0,08	0,03	0,10	0,70	0,50	0,80	0,35	0,25	0,40	0,70	0,50	0,80	1,05	0,75	1,20	0,70	0,50	0,80	0,35	0,25	0,40	0,70	0,50	0,80	0,35	0,25	0,40
Gaziantep	4	1,40	1,00	1,60	0,18	0,12	0,18	1,40	1,00	1,60	0,70	0,50	0,00	1,40	1,00	1,60	2,10	1,50	2,40	1,40	1,00	1,60	0,70	0,50	0,00	1,40	1,00	1,60	0,70	0,50	0,00
Giresun	1	1,40	1,20	1,80	0,12	0,08	0,14	1,40	1,20	1,80	1,40	1,20	0,80	1,40	1,20	1,80	2,10	1,80	2,70	1,40	1,20	1,80	1,40	1,20	0,80	1,40	1,20	1,80	1,40	1,20	0,80
Hatay	4	1,20	1,00	1,10	0,10	0,08	0,08	1,20	1,00	1,10	0,60	0,50	0,55	1,20	1,00	1,10	1,80	1,50	1,65	1,20	1,00	1,10	0,60	0,50	0,55	1,20	1,00	1,10	0,60	0,50	0,55
Isparta	1	1,20	0,80	0,80	0,10	0,08	0,06	1,20	0,80	0,80	0,60	0,40	0,40	1,20	0,80	0,80	1,80	1,20	1,20	1,20	0,80	0,80	0,60	0,40	0,40	1,20	0,80	0,80	0,60	0,40	0,40
İçel	6	1,20	1,00	1,10	0,10	0,08	0,08	1,20	1,00	1,10	0,60	0,50	0,55	1,20	1,00	1,10	1,80	1,50	1,65	1,20	1,00	1,10	0,60	0,50	0,55	1,20	1,00	1,10	0,60	0,50	0,55
İstanbul	77	0,10	0,40	0,60	0,02	0,04	0,08	0,10	0,40	0,60	0,05	0,20	0,30	0,10	0,40	0,60	0,50	0,90	0,90	0,25	0,60	0,80	0,05	0,20	0,30	0,25	0,60	0,80	0,05	0,20	0,30
İzmir	11	0,60	0,60	0,40	0,08	0,08	0,02	0,60	0,60	0,40	0,30	0,30	0,20	0,60	0,60	0,40	0,90	0,90	0,50	0,60	0,60	0,40	0,30	0,30	0,20	0,60	0,60	0,40	0,30	0,30	0,20
K.Maraş	1	1,20	1,00	1,10	0,10	0,08	0,08	1,20	1,00	1,10	0,60	0,50	0,55	1,20	1,00	1,10	1,80	1,50	1,65	1,20	1,00	1,10	0,60	0,50	0,55	1,20	1,00	1,10	0,60	0,50	0,55
Kayseri	4	1,30	0,80	1,30	0,08	0,04	0,10	1,30	0,80	1,30	0,65	0,40	0,65	1,30	0,80	1,30	1,95	1,20	1,95	1,30	1,00	1,30	0,65	0,40	0,65	1,30	1,00	1,30	0,65	0,40	0,65
Kırklareli	1	0,40	1,00	1,20	0,04	0,08	0,10	0,40	1,00	1,20	0,20	0,50	0,60	0,40	1,00	1,20	0,60	1,50	1,80	0,50	1,00	1,20	0,20	0,50	0,60	0,50	1,00	1,20	0,20	0,50	0,60
Kocaeli	3	0,40	0,70	1,00	0,02	0,04	0,08	0,40	0,70	1,00	0,20	0,35	0,50	0,40	0,70	1,00	0,60	1,00	1,50	0,50	0,70	1,00	0,20	0,35	0,50	0,50	0,70	1,00	0,20	0,35	0,50
Konya	3	0,70	0,40	1,00	0,08	0,04	0,08	0,70	0,40	1,00	0,35	0,20	0,50	0,70	0,40	1,00	1,00	0,60	1,50	0,70	0,50	1,00	0,35	0,20	0,50	0,70	0,50	1,00	0,35	0,20	0,50
Malatya	2	1,40	0,90	1,40	0,08	0,04	0,10	1,40	0,90	1,40	0,70	0,45	0,70	1,40	0,90	1,40	2,10	1,35	2,10	1,30	1,00	1,30	0,70	0,45	0,70	1,30	1,00	1,30	0,70	0,45	0,70
Mardin	1	1,60	1,20	1,80	0,18	0,12	0,18	1,60	1,20	1,80	0,80	0,60	0,90	1,60	1,20	1,80	2,40	1,80	2,40	1,80	1,60	2,00	0,80	0,60	0,90	1,80	1,60	2,00	0,80	0,60	0,90
Muğla	1	1,20	1,00	0,40	0,10	0,08	0,02	1,20	1,00	0,40	0,60	0,50	0,20	1,20	1,00	0,40	1,80	1,50	0,60	1,20	1,00	0,40	0,60	0,50	0,20	1,20	1,00	0,40	0,60	0,50	0,20
Ordu	1	1,40	1,20	1,80	0,12	0,08	0,14	1,40	1,20	1,80	0,70	0,60	0,90	1,40	1,20	1,80	2,10	1,80	2,40	1,40	1,20	1,80	0,70	0,60	0,90	1,40	1,20	1,80	0,70	0,60	0,90
Osmaniye	1	1,20	1,00	1,10	0,10	0,08	0,08	1,20	1,00	1,10	0,60	0,50	0,55	1,20	1,00	1,10	1,80	1,50	1,65	1,20	1,00	1,10	0,60	0,50	0,55	1,20	1,00	1,10	0,60	0,50	0,55
Sakarya	3	0,40	0,70	1,00	0,02	0,06	0,08	0,40	0,70	1,00	0,20	0,35	0,50	0,40	0,70	1,00	0,60	1,05	1,50	0,40	0,70	1,00	0,20	0,35	0,50	0,40	0,70	1,00	0,20	0,35	0,50
Samsun	1	1,20	1,00	1,60	0,12	0,08	0,14	1,20	1,00	1,60	0,60	0,50	0,80	1,20	1,00	1,60	1,80	1,50	2,40	1,20	1,00	1,60	0,60	0,50	0,80	1,20	1,00	1,60	0,60	0,50	0,80
Sivas	1	1,30	0,80	1,30	0,08	0,04	0,10	1,30	0,80	1,30	0,65	0,40	0,65	1,30	0,80	1,30	1,95	1,20	1,95	1,30	1,00	1,30	0,65	0,40	0,65	1,30	1,00	1,30	0,65	0,40	0,65
Şanlıurfa	2	1,40	1,00	1,60	0,18	0,12	0,18	1,40	1,00	1,60	0,50	0,50	0,80	1,40	1,00	1,60	2,10	1,50	2,40	1,80	1,60	2,00	0,50	0,50	0,80	1,80	1,60	2,00	0,50	0,50	0,80
Tekirdağ	7	0,40	0,80	1,00	0,04	0,08	0,10	0,40	0,80	1,00	0,20	0,40	0,50	0,40	0,80	1,00	0,60	1,20	1,50	0,40	0,80	1,00	0,20	0,40	0,50	0,40	0,80	1,00	0,20	0,40	0,50
Trabzon	5	1,40	1,20	1,80	0,12	0,08	0,14	1,40	1,20	1,80	0,70	0,60	0,90	1,40	1,20	1,80	2,10	1,80	2,40	1,40	1,20	1,80	0,70	0,60	0,90	1,40	1,20	1,80	0,70	0,60	0,90
Zonguldak	1	0,80	0,60	1,20	0,06	0,05	0,10	0,80	0,60	1,20	0,40	0,30	0,60	0,80	0,60	1,20	1,20	0,90	1,80	0,80	0,60	1,20	0,40	0,30	0,60	0,80	0,60	1,20	0,40	0,30	0,60

Table 5. 600 kilometers coverage between DC and customer zones

City	Adana	Afyon	Ankara	Antalya	Aydın	Balıkesir	Batman	Bolu	Bursa	Çorum	Denizli	Diyarbakır	Edirne
IST	0	1	1	0	0	1	0	1	1	0	0	0	1
ANK	1	1	1	1	1	1	0	1	1	1	1	0	0
IZM	1	1	1	1	1	1	0	0	1	0	1	0	1
City	Erzurum	Eskişehir	Gaziantep	Giresun	Hatay	Isparta	İçel	İstanbul	İzmir	K.Maraş	Kayseri	Kırklareli	Kocaeli
IST	0	1	0	0	0	0	0	1	0	0	0	1	1
ANK	0	1	0	0	0	1	1	1	0	1	1	0	1
IZM	0	1	0	0	0	1	0	0	1	0	0	0	1
City	Konya	Malatya	Mardin	Muğla	Ordu	Osmaniye	Sakarya	Samsun	Sivas	Şanlıurfa	Tekirdağ	Trabzon	Zonguldak
IST	0	0	0	0	0	0	1	0	0	0	1	0	1
ANK	1	0	0	0	1	1	1	1	1	0	1	0	1
IZM	1	0	0	1	0	0	1	0	0	0	1	0	0

Appendix IV. GAMS Model

```
sets
i "Products" /1*10/
j "Raw material suppliers" /1*32/
k "Distribution Centers" /1*7/
z "Demand Zone" /1*39/ ;

variables
Y(i,j,k) "Total number of product i distributed from supplier j to DC k"
X(i,k,z) "Total number of product i distributed from DC k to Demand zone z"
DC(k) "1, if DC is open; otherwise 0"
DCServe(k,z) "1 if DC serves Customer Zone z; otherwise 0"
DemandPrice(i,z) "Demand price impact"
DemandCoverage(i,z) "Demand coverage impact"
TotalDemandCoverage "Total Coverage impact on Demand"
AggregatedDemand "Total Demand"
S1 "1 if Total number of DCs is 1; otherwise 0"
S2 "1 if Total number of DCs is 2; otherwise 0"
S3 "1 if Total number of DCs is 3; otherwise 0"
Demand(i,z) "Demand of product i at Customer Zone z"
TotalDemand(i) "Total Demand of product i - Sum of the demand at each customer
zone"
TotalRevenue "Total Sales revenue for all products"
TotalCosts "Total Costs of the Network"
TotalProfit "Total Costs subtracted from Total Revenues"
TotalSales "Number of Total Sales - aggregated numbers"
TotalInventorycosts "Total Inventory Costs"
TotalLostSalesCosts "Total Costs of Lost Sales due to disruptions"
TotalLostSales "Total Lost Sales due to disruptions"
SCRiskValue "Risk Value"
d1 "Distance from Profit Goal"
d2 "Distance from Sales Goal"
TotalDistance ;

positive variables
Y(i,j,k)
X(i,k,z) ;

binary variables
DC(k)
DCServe(k,z)
S1
S2
S3 ;
```

```
parameters
FixedCosts(k) "Fixed Costs for Distribution Center k"
/1 2500000,2 500000,3 800000,4 1000000,5 500000,6 800000,7 1000000/
capacityDC(k) "Capacity for Distribution Center k"
/1 100000000,2 250000,3 500000,4 1000000,5 250000,6 500000,7 1000000/
PurchCost(i) "Purchasing Cost of Product i"
/1 12,2 1,3 24,4 8,5 8,6 20,7 15,8 10,9 12,10 6/
ShortageCost(i) "Lost Sales Cost of Product i"
/1 6,2 0.5,3 12,4 4,5 4,6 10,7 5,8 5,9 3,10 4/
BasePrice(i) "Current Price of Product i"
/1 18,2 1.5,3 36,4 12,5 12,6 30,7 20,8 15,9 15,10 10/
InvCost1(i) "Inventory costs per item in case of 1 DC"
/1 0.223,2 0.015,3 0.223,4 0.079,5 0.168,6 0.471,7 0.290,8 0.102,9 0.147,10 0.089/
InvCost2(i) "Inventory costs per item in case of 2 DCs"
/1 0.277,2 0.020,3 0.228,4 0.089,5 0.228,6 0.707,7 0.370,8 0.127,9 0.180,10 0.099/
InvCost3(i) "Inventory costs per item in case of 3 DC"
/1 0.297,2 0.022,3 0.240,4 0.107,5 0.240,6 0.722,7 0.483,8 0.135,9 0.202,10
0.117/ ;

scalar
Alpha "Price Elasticity Coefficient" /-2.5/
Beta "One Day Replenishment Coverage Area Elasticity Coefficient" /0.1/
Nu "From Supplier to DC" /0.0025/
Sigma "DC Handdling" /0.005/
Pi "From DC to Customer" /0.01/
TargetSales /2530000/
PriceChange /0.11/
TargetProfit /5550000/ ;

table Supplyrate(i,j)  "Suppy rate for product i from supplier j"
           1       2       3       4       5       6       7       8
1        0.0482  0.4910  0.1085  0.2244  0.1279  0.0000  0.0000  0.0000
2        0.0000  0.0000  0.0000  0.0000  0.0000  1.0000  0.0000  0.0000
3        0.3133  0.0000  0.6867  0.0000  0.0000  0.0000  0.0000  0.0000
4        0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0269  0.3246
5        0.0451  0.1760  0.0000  0.1170  0.1619  0.0000  0.0000  0.1071
6        0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
7        0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
8        0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
9        0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
10       0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
```

table BaseDemand(i,z) "Current Demand of product i at customer zone z"

	1	2	3	4	5	6	7	8	9
1	2305	1140	8258	2837	1988	1634	557	912	7625
2	2322	1449	10052	3615	2509	452	1106	1091	9054
3	271	92	1072	329	236	18	67	101	874
4	10561	2364	36150	11665	8092	1051	2680	3626	31579
5	1149	867	3788	1382	818	119	222	379	3252
6	1968	1830	8939	3341	2349	168	625	1037	9472
7	1468	846	5320	1538	1407	77	338	400	4659
8	8305	4392	26003	11654	7436	174	913	2609	25090
9	11702	2425	46202	12793	10246	667	3699	4911	34014
10	1656	815	6174	1812	1431	52	312	590	5541

table DCOnedayReplenishmentCoverage(k,z) "1, if the distance between DC k and customer zone z is less than 600 km; otherwise 0"

	1	2	3	4	5	6	7	8	9
1	0	1	1	0	0	1	0	1	1
2	1	1	1	1	1	1	0	1	1
3	1	1	1	1	1	1	0	1	1
4	1	1	1	1	1	1	0	1	1
5	1	1	1	1	1	1	0	1	1
6	1	1	1	1	1	1	0	1	1
7	1	1	1	1	1	1	0	1	1

table TransInbound(i,k,j) "Transportation Costs for Product i from Supplier j to DC k"

	1	2	3	4	5	6	7	8	9
1.1	0.20	0.70	0.20	0.20	0.20	5.00	5.00	5.00	
1.2	0.60	0.40	0.65	0.65	0.65	5.00	5.00	5.00	
1.3	0.60	0.40	0.65	0.65	0.65	5.00	5.00	5.00	
1.4	0.60	0.40	0.65	0.65	0.65	5.00	5.00	5.00	
1.5	0.70	0.35	0.70	0.70	0.70	5.00	5.00	5.00	
1.6	0.70	0.35	0.70	0.70	0.70	5.00	5.00	5.00	
1.7	0.70	0.35	0.70	0.70	0.70	5.00	5.00	5.00	
2.1	5.00	5.00	5.00	5.00	5.00	0.05	5.00	5.00	
2.2	5.00	5.00	5.00	5.00	5.00	0.12	5.00	5.00	
2.3	5.00	5.00	5.00	5.00	5.00	0.12	5.00	5.00	
2.4	5.00	5.00	5.00	5.00	5.00	0.12	5.00	5.00	
2.5	5.00	5.00	5.00	5.00	5.00	0.12	5.00	5.00	
2.6	5.00	5.00	5.00	5.00	5.00	0.12	5.00	5.00	
2.7	5.00	5.00	5.00	5.00	5.00	0.12	5.00	5.00	
.									
.									
.									
10.6	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
10.7	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	

table TransOutbound(i,k,z) "Transportation Costs for Product i from DC k to Customer Zone z"

	1	2	3	4	5	6
1.1	1.20	1.00	0.50	1.10	1.20	0.80
1.2	1.00	0.85	0.10	0.90	1.00	0.80
1.3	1.00	0.85	0.10	0.90	1.00	0.80
1.4	1.00	0.85	0.10	0.90	1.00	0.80
1.5	1.10	0.60	0.60	0.80	0.40	0.40
1.6	1.10	0.60	0.60	0.80	0.40	0.40
1.7	1.10	0.60	0.60	0.80	0.40	0.40
2.1	0.10	0.12	0.06	0.10	0.10	0.06
2.2	0.08	0.10	0.02	0.08	0.10	0.08
2.3	0.08	0.10	0.02	0.08	0.10	0.08
2.4	0.08	0.10	0.02	0.08	0.10	0.08
2.5	0.08	0.10	0.08	0.06	0.02	0.06
2.6	0.08	0.10	0.08	0.06	0.02	0.06
2.7	0.08	0.10	0.08	0.06	0.02	0.06
.						
.						
.						
10.6	0.55	0.30	0.30	0.40	0.20	0.20
10.7	0.55	0.30	0.30	0.40	0.20	0.20

equations

```
DemandPriceEffect(i,z),
DemandCoverageEffect(i,z),
TotalDemandCoverage1,
Demand1(i,z) "Total Demand of product i at customer zone z",
TotalDemand1(i) "Total Demand of product i",
AggregatedDemand1,
TotalRevenue1 "Total Revenue of all products",
SuppliedRate(i,j) "Supplied Product Calculation from each Supplier",
TotalCost1 "Total Costs for the whole network",
TotalProfit1 "Total Profit of the whole network",
TotalSales1 "Number of Total Sales - aggregated numbers",
NumberofDCConstr,
NumberofDCConstr2,
TotalInvCosts1,
TotalInvCosts2,
TotalInvCosts3,
TotalRiskCost1,
TotalRiskCost2,
TotalRiskCost3,
TotalLostSales1,
TotalLostSales2,
TotalLostSales3,
SCRiskValue1,
DCTraffic(i,k) "DC inbound and outbound traffic must be equal",
```

```
DemandFill(i,z) "Demand Constraint; Sales can not exceed the demand at each
customer zone",
DCCapacity(k) "Total amount shipped to DC should not exceed DC Capacity",
DCAllocation(z) "Customer zone z is supplied by only one DC",
DCAllocation2(i,k,z)"Customer zone z is supplied by only one DC",
OneDCAnkara "Maximum one DC should be opened in Ankara",
OneDCIzmir "Maximum one DC should be opened in İzmir",
DistanceFunction,
SalesDistance,
ProfitDistance ;

DemandPriceEffect(i,z)..DemandPrice(i,z)=e=Alpha*BaseDemand(i,z)*PriceChange;
DemandCoverageEffect(i,z)..DemandCoverage(i,z)=e=sum(k,Beta*DCOneDayReplenishmentCo
verage(k,z)*DCServe(k,z)*BaseDemand(i,z));
TotalDemandCoverage1..TotalDemandCoverage=e=sum((i,z),DemandCoverage(i,z));
Demand1(i,z)..Demand(i,z)=e=BaseDemand(i,z)+DemandCoverage(i,z)+DemandPrice(i,z);
DC.fx('1')=1;
TotalDemand1(i)..TotalDemand(i)=e=sum((k,z),X(i,k,z));
AggregatedDemand1..AggregatedDemand=e=sum(i,TotalDemand(i));
TotalRevenue1..TotalRevenue=e=Sum(i,TotalDemand(i)*Baseprice(i)*(1+PriceChange))-
TotalLostSalesCosts;
SuppliedRate(i,j)..sum(k,Y(i,j,k))=e=TotalDemand(i)*Supplyrate(i,j);
NumberofDCConstr..sum(k,DC(k))=e=S1+2*S2+3*S3;
NumberofDCConstr2..S1+S2+S3=e=1;
TotalCost1..TotalCosts=e=sum(i,(PurchCost(i)*TotalDemand(i)))+sum((i,j,k),TransInbo
und(i,k,j)*Y(i,j,k))+sum(k,FixedCosts(k)*DC(k))+sum((i,k,z),TransOutbound(i,k,z)*X(
i,k,z))+TotalInventorycosts;
TotalInvCosts1..sum(i,(Invcost1(i)*TotalDemand(i)))-
TotalInventorycosts=l=100000000000*(1-S1);
TotalInvCosts2..sum(i,(Invcost2(i)*TotalDemand(i)))-
TotalInventorycosts=l=100000000000*(1-S2);
TotalInvCosts3..sum(i,(Invcost3(i)*TotalDemand(i)))-
TotalInventorycosts=l=100000000000*(1-S3);
TotalRiskCost1..sum(i,(ShortageCost(i)*TotalDemand(i)*(1-(1-(Nu))*(1-(Sigma))*(1-
(Pi)))))-TotalLostSalesCosts=l=100000000000*(1-S1);
TotalRiskCost2..sum(i,(ShortageCost(i)*TotalDemand(i)*(1-(1-(Nu*Nu))*(1-
(Sigma*Sigma))*(1-(Pi*Pi)))))-TotalLostSalesCosts=l=100000000000*(1-S2);
TotalRiskCost3..sum(i,(ShortageCost(i)*TotalDemand(i)*(1-(1-(Nu*Nu*Nu))*(1-
(Sigma*Sigma*Sigma))*(1-(Pi*Pi*Pi)))))-TotalLostSalesCosts=l=100000000000*(1-S3);
TotalLostSales1..sum(i,(TotalDemand(i)*(1-(1-(Nu))*(1-(Sigma))*(1-(Pi)))))-
TotalLostSales=l=100000000000*(1-S1);
TotalLostSales2..sum(i,(TotalDemand(i)*(1-(1-(Nu*Nu))*(1-(Sigma*Sigma))*(1-
(Pi*Pi)))))-TotalLostSales=l=100000000000*(1-S2);
TotalLostSales3..sum(i,(TotalDemand(i)*(1-(1-(Nu*Nu*Nu))*(1-
(Sigma*Sigma*Sigma))*(1-(Pi*Pi*Pi)))))-TotalLostSales=l=100000000000*(1-S3);
SalesDistance..d2=e=TotalSales - TargetSales;
TotalProfit1..TotalProfit=e=TotalRevenue - TotalCosts;
ProfitDistance..d1=e=TotalProfit - TargetProfit;
TotalSales1..TotalSales=e=sum(i,TotalDemand(i)) - TotalLostSales;
```

```
SCRiskValue1..SCRiskValue=e=(1-Nu)*(1-Sigma)*(1-Pi)*S1+(1-Nu*Nu)*(1-
Sigma*Sigma)*(1-Pi*Pi)*S2+(1-Nu*Nu*Nu)*(1-Sigma*Sigma*Sigma)*(1-Pi*Pi*Pi)*S3;
DistanceFunction..TotalDistance=e=d1+2*d2;
DCTraffic(i,k)..sum(j,Y(i,j,k))=g=sum(z,X(i,k,z));
DemandFill(i,z)..sum(k,X(i,k,z))=l=Demand(i,z);
DCCapacity(k)..sum((i,j),Y(i,j,k))=l=DC(k)*capacityDC(k);
DCAllocation(z)..sum(k,DCServe(k,z))=l=1;
DCAllocation2(i,k,z)..X(i,k,z)=l=DCServe(k,z)*100000000;
OneDCAnkara..DC('2')+DC('3')+DC('4')=l=1;
OneDCIzmir..DC('5')+DC('6')+DC('7')=l=1;

model XYZ /all/;

solve XYZ using MIP maximizing TotalDistance;

Display DC.l;
Display Y.l;
Display X.l;
Display TotalDemandCoverage.l;
Display Demand.l;
Display TotalDemand.l;
Display AggregatedDemand.l;
Display TotalLostSales.l;
Display TotalLostSalesCosts.l;
Display TotalRevenue.l;
Display TotalInventoryCosts.l;
Display TotalCosts.l;
Display SCRiskValue.l;
Display TotalProfit.l;
Display TotalSales.l;
Display TotalDistance.l;
Display DemandCoverage.l;
Display DCServe.l;
```

Appendix V. Model Results – Gams Output

```
GAMS Rev 235  WIN-VS8 23.5.1 x86/MS Windows          02/09/14 14:08:39 Page 1
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
C o m p i l a t i o n
GAMS Rev 235  WIN-VS8 23.5.1 x86/MS Windows          02/09/14 14:08:39 Page 4
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
Model Statistics    SOLVE XYZ Using MIP From line 364


MODEL STATISTICS

BLOCKS OF EQUATIONS          35     SINGLE EQUATIONS        4,761
BLOCKS OF VARIABLES          24     SINGLE VARIABLES        6,446
NON ZERO ELEMENTS        30,283     DISCRETE VARIABLES        282


GENERATION TIME      =        0.094 SECONDS      6 Mb  WIN235-235 Jul  2, 2010


EXECUTION TIME       =        0.094 SECONDS      6 Mb  WIN235-235 Jul  2, 2010




GAMS Rev 235  WIN-VS8 23.5.1 x86/MS Windows          02/09/14 14:08:39 Page 5
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
Solution Report     SOLVE XYZ Using MIP From line 364


               S O L V E      S U M M A R Y

     MODEL   XYZ                 OBJECTIVE  TotalDistance
     TYPE    MIP                 DIRECTION  MAXIMIZE
     SOLVER  CPLEX               FROM LINE  364

**** SOLVER STATUS     1 Normal Completion
**** MODEL STATUS      8 Integer Solution
**** OBJECTIVE VALUE          -804750.7045

 RESOURCE USAGE, LIMIT          6.908      1000.000
 ITERATION COUNT, LIMIT     21620    2000000000

IBM ILOG CPLEX   Jul  4, 2010 23.5.1 WIN 18414.18495 VS8 x86/MS Windows
Cplex 12.2.0.0, GAMS Link 34
GAMS/Cplex licensed for continuous and discrete problems.

Cplex MIP uses 1 of 2 parallel threads. Change default with option THREADS.
MIP status(102): integer optimal, tolerance
Fixed MIP status(1): optimal
```

```
Solution satisfies tolerances.

MIP Solution:       -804750.704461    (21402 iterations, 149 nodes)
Final Solve:        -804750.704461    (218 iterations)

Best possible:      -804412.900610
Absolute gap:           337.803850
Relative gap:             0.000420

GAMS Rev 235  WIN-VS8 23.5.1 x86/MS Windows          02/09/14 14:08:39 Page 6
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
E x e c u t i o n

----    366 VARIABLE DC.L  1, if DC is open; otherwise 0
1 1.000,    2 1.000

----    367 VARIABLE Y.L  Total number of product i distributed from supplier j to DC k
```

	1	2
1 .1	5968.201	
1 .2	46281.406	14515.000
1 .3	13434.644	
1 .4	27785.567	
1 .5	15836.783	
2 .6	134671.500	17614.000
3 .1	2934.242	1750.000
3 .3	10267.058	
4 .7	13799.391	
4 .8	104251.067	62265.000
4 .9	89824.286	
4 .10	16620.827	
4 .11	123322.435	
4 .12	17031.218	
4 .13	34883.218	
4 .14	50991.057	
5 .1	2389.001	
5 .2	3013.931	6309.000
5 .4	6197.630	
5 .5	8576.037	
5 .8	5673.216	
5 .15	20812.384	
6 .16	20285.053	
6 .17	12961.552	
6 .18	98504.195	17404.000
7 .19	65793.967	
7 .20		6452.306
7 .21	966.733	1988.694
8 .19	138183.338	
8 .20	42723.556	
8 .21	5618.548	46354.000
8 .22	9885.391	
8 .23	82477.252	

8 .24	21043.579	
8 .25	77980.036	
9 .26	61786.793	53999.743
9 .27	13569.661	
9 .28		12088.257
9 .29	349789.112	
9 .30	33420.474	
9 .31	15347.345	
9 .32	52560.214	
10.19	12505.389	
10.21	19252.287	9260.000
10.22	14116.253	
10.24	4476.505	
10.25	25171.865	

----368 VARIABLE X.L Total number of product i distributed from DC k to Demand zone z

	1	2	3	4	5	6
1 .1	2074.500	1140.000	8258.000	2553.300	1789.200	1634.000
2 .1	2089.800	1449.000	10052.000	3253.500	2258.100	452.000
3 .1	243.900	92.000	1072.000	296.100	212.400	18.000
4 .1	9504.900	2364.000	36150.000	10498.500	7282.800	1051.000
5 .1	1034.100	867.000	3788.000	1243.800	736.200	119.000
6 .1	1771.200	1830.000	8939.000	3006.900	2114.100	168.000
7 .1	1321.200	846.000	5320.000	1384.200	1266.300	77.000
8 .1	7474.500	4392.000	26003.000	10488.600	6692.400	174.000
9 .1	10531.800	2425.000	46202.000	11513.700	9221.400	667.000
10.1	1490.400	815.000	6174.000	1630.800	1287.900	52.000

+	7	8	9	10	11	12
1 .1	501.300	912.000	7625.000		911.700	1584.900
1 .2				494.000		
2 .1	995.400	1091.000	9054.000		1233.900	1949.400
2 .2				468.000		
3 .1	60.300	101.000	874.000		125.100	182.700
3 .2				47.000		
4 .1	2412.000	3626.000	31579.000		4161.600	6289.200
4 .2				2154.000		
5 .1	199.800	379.000	3252.000		429.300	541.800
5 .2				217.000		
6 .1	562.500	1037.000	9472.000		1249.200	1826.100
6 .2				503.000		
7 .1	304.200	400.000	4659.000		609.300	975.600
7 .2				254.000		
8 .1	821.700	2609.000	25090.000		2621.700	5517.900
8 .2				1826.000		
9 .1	3329.100	4911.000	34014.000		3928.500	7039.800
9 .2				3699.000		
10.1	280.800	590.000	5541.000		601.200	1178.100
10.2				347.000		

+	13	14	15	16	17	18
1 .1	2039.000	398.700	1267.000			1493.100
1 .2				7105.000	355.000	
2 .1	2182.000	462.600	1558.000			1542.600
2 .2				9042.000	312.000	
3 .1	203.000	42.300	153.000			153.000
3 .2				852.000	34.000	
4 .1	7934.000	1844.100	5202.000			8133.300
4 .2				29477.000	631.000	
5 .1	656.000	195.300	537.000			687.600
5 .2				3230.000	184.000	
6 .1	2837.000	452.700	1525.000			1853.100
6 .2				9152.000	336.000	
7 .1	1107.000	228.600	769.000			767.700
7 .2				4228.000	169.000	
8 .1	5131.000	1604.700	2913.000			5909.400
8 .2				22655.000	1478.000	
9 .1	7822.000	1800.900	5336.000			7694.100
9 .2				31771.000	2607.000	
10.1	1171.000	367.200	789.000			1124.100
10.2				4344.000	338.000	

+	19	20	21	22	23	24
1 .1	239.400	2279.700	52486.000	4263.300	581.400	
1 .2						2685.000
2 .1	182.700	2594.700	67213.000	5133.600	589.500	
2 .2						3288.000
3 .1	23.400	296.100	6459.000	467.100	92.700	
3 .2						347.000
4 .1	520.200	9458.100	215429.000	15747.300	4728.600	
4 .2						10509.000
5 .1	121.500	975.600	22571.000	1877.400	288.000	
5 .2						1095.000
6 .1	164.700	3047.400	63882.000	5216.400	576.900	
6 .2						2852.000
7 .1	165.600	1099.800	33064.000	2566.800	352.800	
7 .2						1707.000
8 .1	861.300	8100.900	182503.000	16123.500	1565.100	
8 .2						6392.000
9 .1		11677.500	255988.000	24228.900	2782.800	
9 .2						12611.000
10.1	397.800	1623.600	36418.000	3059.100	437.400	
10.2						1682.000

+	25	26	27	28	29	30
1 .1	684.000	2444.000			569.700	684.000
1 .2			1824.000	1393.000		
2 .1	701.000	2945.000			603.000	939.600
2 .2			2182.000	1543.000		
3 .1	63.000	301.000			96.300	75.600
3 .2			216.000	170.000		
4 .1	2522.000	10509.000			2458.800	2884.500

4 .2			8249.000	8092.000		
5 .1	298.000	1084.000			238.500	297.000
5 .2			710.000	602.000		
6 .1	839.000	3768.000			603.900	700.200
6 .2			1846.000	1785.000		
7 .1	384.000	1407.000			276.300	200.700
7 .2			838.000	853.000		
8 .1	2392.000	9219.000			2387.700	2543.400
8 .2			6175.000	5175.000		
9 .1	3941.000	7336.000			2182.500	2292.300
9 .2			6063.000	6063.000		
10.1	512.000	1647.000			351.000	381.600
10.2			910.000	1075.000		

+	31	32	33	34	35	36
1 .1	319.500	307.800	1647.000	1823.400		501.300
1 .2					659.000	
2 .1	421.200	392.400	1730.000	2173.500		701.100
2 .2					779.000	
3 .1	45.000	54.000	216.000	221.400		109.800
3 .2					84.000	
4 .1	1891.800	1891.800	6200.000	7897.500		3499.200
4 .2					3153.000	
5 .1	112.500	199.800	721.000	575.100		243.900
5 .2					271.000	
6 .1	480.600	425.700	1785.000	2210.400		713.700
6 .2					930.000	
7 .1	324.900	242.100	899.000	1162.800		304.200
7 .2					392.000	
8 .1	1644.300	1291.500	6131.000	6692.400		2621.700
8 .2					2653.000	
9 .1	3329.100	1200.600	8731.000	7694.100		
9 .2					3274.000	
10.1	359.100	140.400	1430.000	1217.700		225.900
10.2					564.000	

+	37	38	39
1 .1	3116.000	2633.400	545.000
2 .1	3756.000	4347.900	624.000
3 .1	384.000	332.100	136.000
4 .1	13399.000	10923.300	2731.000
5 .1	1214.000	990.000	189.000
6 .1	3829.000	3446.100	1418.000
7 .1	2160.000	1515.600	600.000
8 .1	11350.000	10215.000	4827.000
9 .1	16189.000	13369.500	9095.000
10.1	1873.000	1186.200	1170.000

---- 369 VARIABLE TotalDemandCoverage.L = 171765.300

---- 370 VARIABLE Demand.L Demand of product i at Customer Zone z

	1	2	3	4	5	6
1	2074.500	1140.000	8258.000	2553.300	1789.200	1634.000
2	2089.800	1449.000	10052.000	3253.500	2258.100	452.000
3	243.900	92.000	1072.000	296.100	212.400	18.000
4	9504.900	2364.000	36150.000	10498.500	7282.800	1051.000
5	1034.100	867.000	3788.000	1243.800	736.200	119.000
6	1771.200	1830.000	8939.000	3006.900	2114.100	168.000
7	1321.200	846.000	5320.000	1384.200	1266.300	77.000
8	7474.500	4392.000	26003.000	10488.600	6692.400	174.000
9	10531.800	2425.000	46202.000	11513.700	9221.400	667.000
10	1490.400	815.000	6174.000	1630.800	1287.900	52.000

+	7	8	9	10	11	12
1	501.300	912.000	7625.000	494.000	911.700	1584.900
2	995.400	1091.000	9054.000	468.000	1233.900	1949.400
3	60.300	101.000	874.000	47.000	125.100	182.700
4	2412.000	3626.000	31579.000	2154.000	4161.600	6289.200
5	199.800	379.000	3252.000	217.000	429.300	541.800
6	562.500	1037.000	9472.000	503.000	1249.200	1826.100
7	304.200	400.000	4659.000	254.000	609.300	975.600
8	821.700	2609.000	25090.000	1826.000	2621.700	5517.900
9	3329.100	4911.000	34014.000	3699.000	3928.500	7039.800
10	280.800	590.000	5541.000	347.000	601.200	1178.100

+	13	14	15	16	17	18
1	2039.000	398.700	1267.000	7105.000	355.000	1493.100
2	2182.000	462.600	1558.000	9054.000	312.000	1542.600
3	203.000	42.300	153.000	852.000	34.000	153.000
4	7934.000	1844.100	5202.000	29477.000	631.000	8133.300
5	656.000	195.300	537.000	3230.000	184.000	687.600
6	2837.000	452.700	1525.000	9152.000	336.000	1853.100
7	1107.000	228.600	769.000	4228.000	169.000	767.700
8	5131.000	1604.700	2913.000	22655.000	1478.000	5909.400
9	7822.000	1800.900	5336.000	31771.000	2607.000	7694.100
10	1171.000	367.200	789.000	4344.000	338.000	1124.100

+	19	20	21	22	23	24
1	239.400	2279.700	52486.000	4263.300	581.400	2685.000
2	182.700	2594.700	67213.000	5133.600	589.500	3288.000
3	23.400	296.100	6459.000	467.100	92.700	347.000
4	520.200	9458.100	215429.000	15747.300	4728.600	10509.000
5	121.500	975.600	22571.000	1877.400	288.000	1095.000
6	164.700	3047.400	63882.000	5216.400	576.900	2852.000
7	165.600	1099.800	33064.000	2566.800	352.800	1707.000
8	861.300	8100.900	182503.000	16123.500	1565.100	6392.000
9		11677.500	255988.000	24228.900	2782.800	12611.000
10	397.800	1623.600	36418.000	3059.100	437.400	1682.000

+	25	26	27	28	29	30
1	684.000	2444.000	1824.000	1393.000	569.700	684.000
2	701.000	2945.000	2182.000	1543.000	603.000	939.600
3	63.000	301.000	216.000	170.000	96.300	75.600

4	2522.000	10509.000	8249.000	8092.000	2458.800	2884.500
5	298.000	1084.000	710.000	602.000	238.500	297.000
6	839.000	3768.000	1846.000	1785.000	603.900	700.200
7	384.000	1407.000	838.000	853.000	276.300	200.700
8	2392.000	9219.000	6175.000	5175.000	2387.700	2543.400
9	3941.000	7336.000	6063.000	6063.000	2182.500	2292.300
10	512.000	1647.000	910.000	1075.000	351.000	381.600

+	31	32	33	34	35	36
1	319.500	307.800	1647.000	1823.400	659.000	501.300
2	421.200	392.400	1730.000	2173.500	779.000	701.100
3	45.000	54.000	216.000	221.400	84.000	109.800
4	1891.800	1891.800	6200.000	7897.500	3153.000	3499.200
5	112.500	199.800	721.000	575.100	271.000	243.900
6	480.600	425.700	1785.000	2210.400	930.000	713.700
7	324.900	242.100	899.000	1162.800	392.000	304.200
8	1644.300	1291.500	6131.000	6692.400	2653.000	2621.700
9	3329.100	1200.600	8731.000	7694.100	3274.000	
10	359.100	140.400	1430.000	1217.700	564.000	225.900

+	37	38	39
1	3116.000	2633.400	545.000
2	3756.000	4347.900	624.000
3	384.000	332.100	136.000
4	13399.000	10923.300	2731.000
5	1214.000	990.000	189.000
6	3829.000	3446.100	1418.000
7	2160.000	1515.600	600.000
8	11350.000	10215.000	4827.000
9	16189.000	13369.500	9095.000
10	1873.000	1186.200	1170.000

---- 371 VARIABLE TotalDemand.L Total Demand of product i - Sum of the demand at each customer zone

1 123821.600, 2 152285.500, 3 14951.300, 4 512988.500
5 52971.200, 6 149154.800, 7 75201.700, 8 424265.700
9 592561.600, 10 84782.300

---- 372 VARIABLE AggregatedDemand.L = 2182984.200

---- 373 VARIABLE SCRiskValue.L = 0.999

---- 374 VARIABLE TotalLostSales.L = 1145.952

---- 375 VARIABLE TotalLostSalesCosts.L = 4917.722

---- 376 VARIABLE TotalRevenue.L = 3.313561E+7 Total Sales revenue for all products

---- 377 VARIABLE TotalInventorycosts.L = 400699.952

```
----     378 VARIABLE TotalCosts.L          =  2.769404E+7  Total Costs of the Network

----     379 VARIABLE TotalProfit.L         =  5441572.800  Total Costs subtracted from
Total Revenues

----     380 VARIABLE TotalSales.L          =  2181838.248  Number of Total Sales
aggregated numbers

----     381 VARIABLE d1.L                  =  -108427.200

----     382 VARIABLE d2.L                  =  -348161.752

----     383 VARIABLE TotalDistance.L       =  -804750.704

----     384 VARIABLE DemandCoverage.L  Demand
```

	2	3	6	8	9	10
1	114.000	825.800	163.400	91.200	762.500	49.400
2	144.900	1005.200	45.200	109.100	905.400	46.800
3	9.200	107.200	1.800	10.100	87.400	4.700
4	236.400	3615.000	105.100	362.600	3157.900	215.400
5	86.700	378.800	11.900	37.900	325.200	21.700
6	183.000	893.900	16.800	103.700	947.200	50.300
7	84.600	532.000	7.700	40.000	465.900	25.400
8	439.200	2600.300	17.400	260.900	2509.000	182.600
9	242.500	4620.200	66.700	491.100	3401.400	369.900
10	81.500	617.400	5.200	59.000	554.100	34.700

+	13	15	16	17	21	24
1	203.900	126.700	710.500	35.500	5248.600	268.500
2	218.200	155.800	905.400	31.200	6721.300	328.800
3	20.300	15.300	85.200	3.400	645.900	34.700
4	793.400	520.200	2947.700	63.100	21542.900	1050.900
5	65.600	53.700	323.000	18.400	2257.100	109.500
6	283.700	152.500	915.200	33.600	6388.200	285.200
7	110.700	76.900	422.800	16.900	3306.400	170.700
8	513.100	291.300	2265.500	147.800	18250.300	639.200
9	782.200	533.600	3177.100	260.700	25598.800	1261.100
10	117.100	78.900	434.400	33.800	3641.800	168.200

+	25	26	27	28	33	35
1	68.400	244.400	182.400	139.300	164.700	65.900
2	70.100	294.500	218.200	154.300	173.000	77.900
3	6.300	30.100	21.600	17.000	21.600	8.400
4	252.200	1050.900	824.900	809.200	620.000	315.300
5	29.800	108.400	71.000	60.200	72.100	27.100
6	83.900	376.800	184.600	178.500	178.500	93.000
7	38.400	140.700	83.800	85.300	89.900	39.200
8	239.200	921.900	617.500	517.500	613.100	265.300
9	394.100	733.600	606.300	606.300	873.100	327.400
10	51.200	164.700	91.000	107.500	143.000	56.400

+	37	39
1	311.600	54.500
2	375.600	62.400
3	38.400	13.600
4	1339.900	273.100
5	121.400	18.900
6	382.900	141.800
7	216.000	60.000
8	1135.000	482.700
9	1618.900	909.500
10	187.300	117.000

---- 385 VARIABLE DCServe.L 1 if DC seres Customer Zone z; otherwise 0

	1	2	3	4	5	6
1	1.000	1.000	1.000	1.000	1.000	1.000

+	7	8	9	10	11	12
1	1.000	1.000	1.000		1.000	1.000
2				1.000		

+	13	14	15	16	17	18
1	1.000	1.000	1.000			1.000
2				1.000	1.000	

+	19	20	21	22	23	24
1	1.000	1.000	1.000	1.000	1.000	
2						1.000

+	25	26	27	28	29	30
1	1.000	1.000			1.000	1.000
2			1.000	1.000		

+	31	32	33	34	35	36
1	1.000	1.000	1.000	1.000		1.000
2					1.000	

+	37	38	39
1	1.000	1.000	1.000

EXECUTION TIME = 0.032 SECONDS 3 Mb WIN235-235 Jul 2, 2010

Curriculum Vitae

NAME OF AUTHOR: Canser Bilir

PLACE OF BIRTH: Izmit / Turkey

DATE OF BIRTH: 15 October, 1975

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED

MBA&Graduate Cert. in SC and Logistics:	University of Missouri St. Louis
B. Science - Managerial Economics:	Istanbul Technical University

DEGREES AWARDED

B. Science - Managerial Economics:	Istanbul Technical University, 1997
Master of Business Administration:	Istanbul Technical University, 2001
Master of Business Administration:	University of Missouri – St. Louis, 2004
Graduate Certificate in SC and Logistics	University of Missouri – St. Louis, 2004

PROFESSIONAL EXPERIENCE

Head of Strategic PMO, Kuveyt Turk	2005-
Logistics Manager, Aydın Orme, Domeks	2004-2005
Research Assistant, Center for Transportation Studies, University of Missouri St. Louis	2001-2004
Business Analyst, Management Consultant – Performans Consulting	1998-2000