YAŞAR UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

CAPACITATED WAREHOUSE LOCATION PROBLEM FOR A FISH FEED COMPANY IN MUGLA

TUNA ÖZBEK

12400009016

THESIS ADVISOR: ASSOC. PROF. DR. BANU YETKİN EKREN

INDUSTRIAL ENGNEERING

PRESENTATION DATE: 26.08.2019

BORNOVA/İZMİR
NOVEMBER 2019

We certify that, as the jury, we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Jury Members: **Signature:**

Assoc. Prof. Banu Yetkin Ekren
Yasar University ....

Assoc. Prof. Yücel Öztürkoğlu
Yasar University ....

Asst. Prof. Dr. Erkan Kabak
İzmir Ekonomi University ....

Prof. Cüneyt Güzeliş
Director of the Graduate School

ABSTRACT

CAPACITATED WAREHOUSE LOCATION PROBLEM

FOR A FISH FEED COMPANY IN MUGLA

Özbek, Tuna

Msc, Industrial Engineering

Advisor: Assoc. Prof. Banu YETKIN EKREN

June 2019

This thesis is a warehouse location study for a fish feed company aiming to solve a transportation model by also including the warehouse opening decision. The company has several customers spreading all over the region in Turkey. It is important to serve customers on time with a decreased cost. Therefore, this study also focuses on the optimal decision of assigning customers to proper warehouses. Number of warehouses and their potential locations are pre-defined by considering the regions of the customers. For that, several scenarios are created for locating the warehouses in different regions. Later, these potential locations are considered as different scenarios in the developed mathematical models. The models are solved to find out the optimal assignment of customers to pre-defined warehouse group locations. The mathematical model also includes the decision of which warehouses to open. The objective function is considered to be the minimization of total transportation cost and fixed cost for opening a warehouse. This model is solved for different pre-defined warehouse location scenarios and capacity parameters and their total cost results are compared with each other. The best ones with minimal costs based on the scenarios are suggested to the manager for the the solution of the problem.

Key Words: Warehouse location, transportation model, capacitated warehouse problem, location optimization

ÖZ

MUĞLA'DA BİR BALIK YEMİ FABRİKASI İÇİN DEPO LOKASYONU VE YETKİLENDİRMESİ PROBLEMİ

Özbek, Tuna
Yüksek Lisans, Endüstri Mühendisliği
Danışman: Doç. Dr. Xxx YYY
Yardımcı Danışman: Yrd.Doç./Doç./Prof. Dr. Banu YEKİN EKREN
Haziran 2019

Bu tez, depo açma kararını da dahil ederek bir taşıma modelini çözmeyi amaçlayan bir balık yemi şirketi için hazırlanmıştır. Şirketin Türkiye'nin her yerine yayılmış birden fazla müşterisi vardır. Müşterilere zamanında ve düşük maliyetle hizmet vermek önemlidir. Bu nedenle, bu çalışma müşterileri uygun depolara atamanın en uygun kararına odaklanmıştır. Müşteri bölgeleri dikkate alınarak depo ve lokasyon sayısı önceden belirlenmiştir. Bunun için farklı bölgelerdeki depoları bulmak için çeşitli senaryolar oluşturulmuştur. Daha sonra, bu potansiyel yerler gelişmiş matematiksel, ulaştırma modeline dahil edilir ve müşterilerin konumlara en uygun şekilde atamasının yapılması için çözülür. Matematiksel model ayrıca hangi depoların açılacağına karar verir. Amaç, bir depo açmak; için sabit maliyetle birlikte toplam nakliye maliyetinin en az olduğu senaryoya yaklaşmaktır. Bu model, önceden tanımlanmış farklı depo yer senaryoları ve kapasite parametreleri için çözülmüş ve toplam maliyet sonuçları birbiriyle karşılaştırılmıştır. En iyisi, asgari toplam maliyet sağlayan senaryoya göre seçilir.

Anahtar Kelimeler: depo yerleşimi, sevkiyat modeli, kapasiteli depo problemi, yerleşim en iyilemesi

ACKNOWLEDGEMENTS

First, I would like to thank my supervisor Assoc. Prof. Dr. Banu YETKIN EKREN for her guidance and her trust to me in this work.

In addition, I would like to thank all special people who roles in my life. All of you are very important for me.

Tuna Özbek

İzmir, 2019

TEXT OF OATH

I declare and honestly confirm that my study, titled "CAPACITATED WAREHOUSE LOCATION PROBLEM FOR A FISH FEED COMPANY IN MUGLA" and presented as a Master's Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Tuna Özbek

Signature

…………………………………..

November 19, 2019

TABLE OF CONTENTS

SYMBOLS

n : Number of potential warehouse locations

m : Number of customers (demand points)

D_j : Annual demand of customer j

f_i : Annual fixed cost of keeping warehouse i open

c_{ij} : Transportation cost from warehouse i to customer j

Cap_i : Capacity of warehouse i

CHAPTER 1
INTRODUCTION

1.1. Introduction

In today's competitive environment, the efficient and effective movement of goods from raw material manufacturers, production facilities, intermediate manufacturers and finished product assembly factories to distribution centers (i.e., warehouses), retailers and customers has become an important issue. For instance, according to Ballou (1999) supply-related costs account for about 12% of the world's gross national product. In addition, according to Thomas and Griffin (1996), annual logistics expenditures other than military activities are estimated to be more than 11% of the gross national product. According to a global production benchmarking study conducted by Deloitte Global (2003), only 7% of the companies successfully manage their supply chain. It is also declared that companies that successfully manage this process are on average 73% more profitable than the other companies.

Supply chain design decision is a strategic decision. In making this strategic decision, it is important to determine the locations of production facilities and warehouses, the capacities of the relevant facilities and the warehouses to be supplied by the producer, the customers to be distributed to the warehouses, and the assignment of demand centers to the warehouses.

This thesis focuses on the topic of capacitated warehouse location problem (CWLP) for a fish feed company in Turkey. CWLP is a part of supply chain problem, where the objective is to find out the optimal warehouse locations and assignment of customers to those locations. Therefore, first it will be helpful to explain supply chain and its components.

1.1.1. What is Supply Chain and Its Components?

The complex logistics systems in which raw materials are converted into products or services and delivered to end users are called Supply Chains. Supply chain management can be defined as all managerial tasks for the mutual flow of materials and information between suppliers and customers throughout supply chains. Supply chain management processes and operational excellence are critical to the sustainable success of organizations in today's challenging economic and competitive conditions. The main objectives for supply chain excellence are as follows:

- Increasing the value generated throughout the supply chain
- Procurement to increase competitiveness
- Regulation of production and logistics processes
- Ensuring coordination and cooperation to balance demand and supply
- Continuous improvement of all supply chain processes

Organizations should continually assess and restructure supply chains in the presence of ever-changing factors such as their current status, capabilities, competitive conditions and market dynamics.

1.1.2. What are The Elements to be Dealt With In Restructuring a Supply Chain?

Facilities, stocks, transportation, information, procurement and pricing should be considered when structuring supply chains. For each, multiple decision alternatives, variables or costs related to the supply chains can be listed. Most of these are summarized in Figure 1.

facilities	stocks	transportation	information	procurement	pricing
Type&number of facilities	safety stock	shipping network design	data and information	produce or buy	profit margins
facility locations	stock variety	Shipping speed	estimates	supplier selection	value based price
plant capacities	stock positioning	shipping capacities	planning decisions	price bargains	cost based price
fixed costs	discarded stocks	shipping costs	performance measures	deadlines	price ranges
variable costs	Rework stock	shipping restrictions	technologies	purchase quantities	dynamic pricing
...	...	...	...	...	...

Figure 1: Parameters considered in restructuring supply chains

Performance of the existing structure, possible risks, advantages, etc. criteria should be systematically followed and, if necessary, Supply Chain Restructuring and Process Improvement activities should be put on the agenda.

1.1.3. What are The Main Activities within The Scope of Restructuring and Improvement?

Corporate business processes can be classified as follows depending on different decision-making horizons. The activities within the scope restructuring supply chain is summarized below.

1.1.3.1. Supply Chain Structuring Through Chain Strategies

It is the process in which management determines the physical structure of the supply chain through strategic decisions. Within this scope of the physical structure of the supply chain, suppliers, factories, warehouses, etc. the locations and structures of the facilities and the methods and forms of inter-facility transportation are determined.

1.1.3.2. Sales and Operations Planning (S&OP)

With the S&OP process and the planning and decision-making mechanisms involved, it is ensured to balance the supply volumes that can be provided by the anticipated demand. This balancing is achieved in line with strategic objectives that will increase profitability. It is the basic process that will ensure coordination and coordination between departments.

1.1.3.3. Cooperative Planning, Forecasting and Inventory Renewal, CPFR

Through these processes, the organization aims to form its activities in cooperation with its customers and suppliers. The importance of structuring CPFR processes is increasing day by day considering not only companies but also supply chains competing with each other. Various problems arising from the lack of cooperation in the supply chain, causing the Bullwhip Effect, can be eliminated in this way. In this context, cooperation in planning, forecasting and stock renewal cooperation processes are structured and implemented respectively.

1.1.3.4. Demand Planning and Forecasting

Demand planning decisions and predictions for future customer demands are created. These predictions include the company's future workforce, equipment, raw materials, and so on. needs. The without demand forecast may practice serious problems in determining sales and turnover targets and keeping costs under control.

1.1.3.5. Lean Manufacturing, Constraint Theory and Quality Management

In this concept, processes (procurement, production, warehousing, logistics, sales, etc.) are continuously improved systematically, here it results with increased the level of service provided to customers and reduced costs.

1.1.3.6. Order Management, Production, Inventory and Logistics Planning, Purchasing Management

Short-term supply chain management processes that require interdepartmental collaboration and integration.

Customer satisfaction, timely and complete delivery performance and the costs that will arise depend on the effective management and success of these processes:

1.1.3.6.1. Order Management

Decisions such as promises of future delivery or capacity allocation to customers, ordering policies, evaluation of changes and updating of plans as needed are considered within this scope.

1.1.3.6.2. Production Planning and Scheduling

Production lot sizes and delivery schedules are determined so that customer orders and demand forecasts are met. Capacities and material requirements for production are envisaged and action is taken in order to solve possible problems. Again within the scope of production planning, but very short-term Detailed Scheduling decisions to be completed with the tasks or tasks which machine, worker, etc. time intervals by the resources and the flow of the works are determined in detail.

1.1.3.6.3. Purchasing Management

Timing and quantity decisions for the procurement of all kinds of raw materials to be used in production or service delivery from suppliers are determined. Supplier selection, relations and price negotiations are handled within this scope. Supply chain management plays a critical role in these different corporate decision-making and implementation activities. Improvements in supply chain strategies, operations and operation will improve performance throughout the organization.

1.1.3.6.4. Inventory Management, Warehouse and Logistics Planning

Inventory management policies, stock analysis and decisions to create stock and activities such as storage, distribution and transportation are carried out in order to prepare all kinds of materials in the right place at the right time along the supply chain. The study of this thesis can be seen as a part of this step.

This step deals with stock planning, ordering raw materials and commercial products for producers, and planning production orders for semi-finished and finished products. It requires determination and management of stock levels to meet customer demands, while taking into account purchasing, production, warehouse and shipping constraints. The necessity to keep the investment and other costs of stocks under control is one of the important factors that make inventory management difficult. It is necessary to handle stock management together with logistics and distribution planning when it is necessary to ship and locate inventory levels between different institutions and facilities within the supply chain. The facilities in which stocks are stored, sorted and combined are called warehouses. So many decisions are required to be considered in planning of the warehouse decisions.

Logistics deals with the planning and control of material flows from plant to plant along the supply chain in organizations, and information related to these flows. Logistics tries to prepare the right material in the right place at the right time. In doing so, the existing limitations must be observed and the performance measures determined should be optimized. Transport or distribution services and interconnected facilities form a Logistics System. Logistics deals with the planning and control of material flows from plant to plant along the supply chain in organizations, and information related to these flows. Logistics tries to prepare the right material in the right place at the right time. In doing so, the existing limitations must be observed and the performance measures should be optimized.

The main objectives of Supply Chain Management are to keep the level of service provided to the customer at a high level and to reduce the total logistics costs. The existence of these two objectives, which are in trade-offs, is the main factor that makes it difficult to plan logistics systems within supply chains.

Institutions that can make this planning and then implement them correctly and effectively can provide significant advantages over their competitors. For that, an optimization model is developed to make a decision whether or not to open warehouse/warehouses in pre-defined regions and which customers to assin to those opened warehouses. By that model, it is aimed to deliver products to customers in a short time with decreased cost. Hence, the customer satisfaction is also aimed to increase.

1.2. Real Life Observations and Farmers' Conditions

The case study of the transportation model of this thesis is implemented for a fish feed company in Turkey. In order to understand the difficulties that these companies experience in practice, it will be beneficial to summarize the production and the delivery process of the feed process.

All the animals (from now we will call it as fish because of the thesis topic) have different nutritional needs according to their ages (for instance new born fish requires higher protein but lower energy, while the adult fish requires just vice versa), according to the species (sea bream needs less energy than sea bass while rainbow trout needs more plant protein because they eat more plant sources in their natural habitat etc.) and according to the water conditions (water temperature, oxygen level, currency, salinity etc.). For instance, rainbow trout cannot digest fat above twenty two degrees while sea bass has the similar problem above 26 degrees Celcius. If they eat at those water temperatures, their liver is directly damages and we need to use different raw material sources and vitamins to protect the liver in that conditions. The nutritional needs are not the only parameters changing in that case, the consumption of the feed per fish is also changing with the water temperature and oxygen level. For instance marine fish (sea bream, sea bass and meager etc) are consuming almost the triple of what they are consuming in winter time). Actually it is just the opposite for trout and salmon.

This shows that there is no unique product or formula in feed business. When it comes to raw materials side, the complexity gets bigger. There is no stable raw material in agriculture. For instance fishmeal and oil is one of the main sources of the fish feed. They are produced from many different species (anchovy, sardine, mackerel etc) with some specific processes. But even it has been produced from the same species and we buy from the same supplier one bulk of shipment never be the same with the second one in terms of nutritional characteristics. Because even the depth of the water or their stress levels during their catch may affect the taste or fat level of their body flesh which leads to a different nutritional result in fish meal and oil. Therefore, we need to produce always the same feed for the same fish but with constantly changing raw material set.

In fish feed business approximately 80% of the raw material is imported from different countries where some have ninety days of lead times including custom clearance. Although there are hundreds of variables in that business, unfortunately customers are extremely bad at giving precise forecast for their consumption levels for the coming days. Even it is so common that the customer suddenly calls with excitement and says that they ran out of feed he needs feed urgently. So the feed company should be prepared for any unexpected situation that may break their production plan.

Although it is costly, one of the solution is to carry different types of feeds for each and every client. However, sometimes this solution may not solve the puzzle because of the distance of the factory and farm(s).

Turkey has almost a rectangular shape country and the studied fish feed factory is located in Bodrum region, southwest of Turkey. However, farms are dispersed all around of Anatolia, from east to west and north to south. Therefore, sometimes it gets four days to reach to the site by truck even though you have the feed ready on hand and sometimes four days is so critical to lose the millions of fish, meaning millions of dollars.

This means that feed companies should also keep the stock ready within the closest locations to customer sites. When we consider more than one hundred fifty customers to work with, of course it is impossible to keep the ready to use stock in each customer site.

As considering the cost of transport, carrying stock and operating a warehouse, the question is that where to locate the warehouse and by which warehouse to serve the customers. In this thesis, our aim is to solve a warehouse opening decision problem by a transportation model and compare several scenarios' results to select the best of them. A mathematical model is developed for this problem and solved by using Linear Programming approach. For simplicity, we assume that demand profile is fixed in terms of type and amount as well as cost parameters are also fixed based on the unit demand.

CHAPTER 2
TERMINOLOGY and RESEARCH BAKGROUND

2.1. Linear Programming

Since we use a mathematical modelling approach (linear programming) for the solution of the problem, we explain the utilized technique in this section. Linear programming is a kind of mathematical technique to find out the best optimal (feasible) solution for an objective through some set of limitations (constraints). Objective can either be a maximization or minimization of a function. The basic components of linear programming are as follows:

- Decision variables: These are the variables whose optimal levels are to be determined.
- Objective function: This represents how each decision variable would affect the cost, or, simply, the value that needs to be optimized.
- Constraints: These represent the limitations of the decision variables.
- Data: These quantify the relationships between the objective function and the constraints.

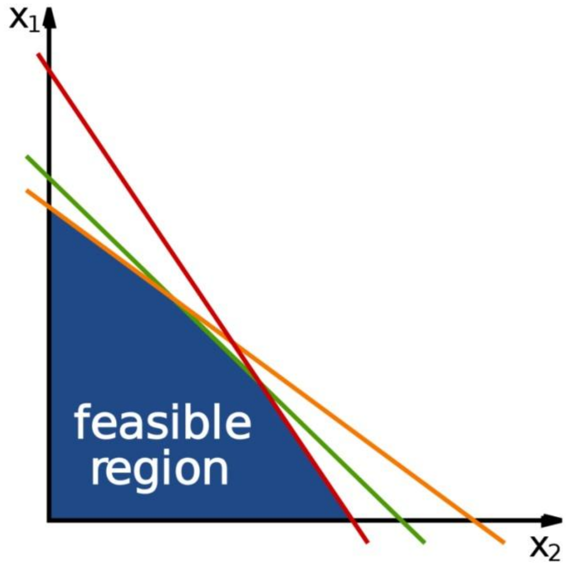

Figure 2: Graph-based solution representing a linear programming

In real life, while we would like to maximize our earnings or minimize the inputs or costs, we may face with many obstacles and limitations. Therefore, it is always more realistic to find the optimum (feasible) as shown in Figure 2, rather than the maximum or minimum. Therefore, Linear Programming (LP) is bringing more realistic approach to our real lives. It is a very effective tool to be used in economics and many areas of industry. While simple LP models can be solved by graphical or matrix (simplex) methods, in general there are different software tools to solve more complex LP models. In this thesis, we use IBM ILOG CPLEX software to solve the mathematical models.

2.2. Network Design in the Supply Chain

Supply Chain is the whole set of processes for the flow of products and raw materials from suppliers to the factories and from factories through the end users. It includes any process like procurement, planning, transport/shipping, storing goods and distribution channels etc. Simply, we can show this flow in Figure 3:

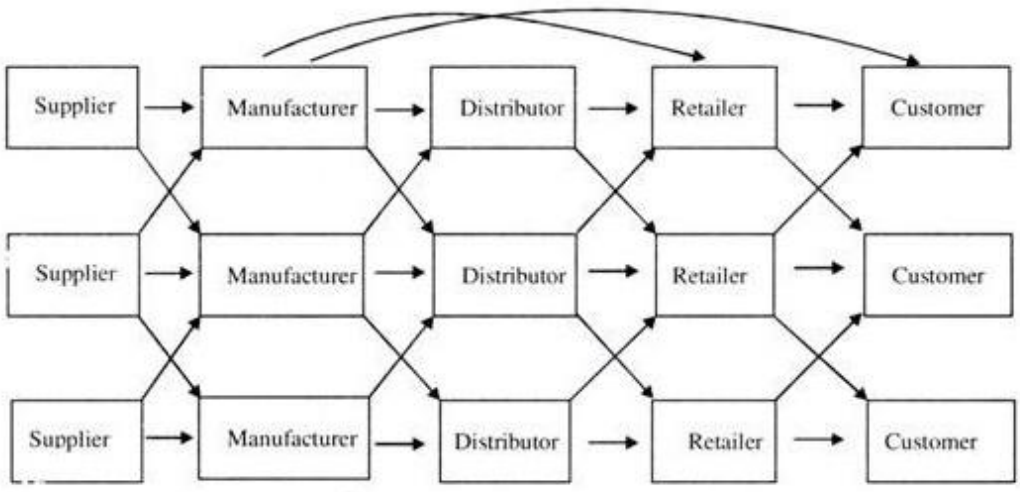

Figure 3: Typical supply chain network design

In real life, many times to plan this network effectively have the crucial importance to have the least lead-time with a minimum cost.

2.3. Capacitated Warehouse Location Problem

In this thesis, we focus on a real case problem. In a simpler way to show the mentality behind this network problem of our example fish feed factory, we complete an extensive literature review in the following section. For the solution, we develop different scenarios for a number of warehouses as well as its capacities in different pre-defined locations. Locations are found hypothetically by considering the cost of transport and the current location of customers. By the developed mathematical model, by the trial of different capacitated warehouse scenarios, we also define the proper capacity of the warehouses to open.

2.4. Research Background

In the simplest problem formulated by Balinski (1965), there are linear costs proportional to a single product, unlimited plant capacity, flowing product quantity and number of plants in operation. There is at least one optimal solution to the problem, which aims to minimize the total network cost. Since there is no capacity constraint, this solution can be reached with the assignment management to the nearest open facility.

According to the problem classification of Djamschidi (1998), the problem represented with the objective function is called multi-site settlement problem. Unlike some other settlement problems, multiple facilities can respond to customer requests. To determine a linear transport cost, the locations of all facilities are determined simultaneously. In addition, shipments between different facilities are also examined.

Many solution methods have been proposed for the fixed cost facility location problem. Kuehn and Hamburger (1963) proposed an intuitive method of overlaying and deflecting routines with the main program in order to solve the problem of positioning the warehouses. The main program places the repositories until no more repositories can be opened without increasing the total network cost. The solution is then exchanged with the working routine by sieving other repositories or moving one of the repositories to the location of one of the already opened repositories and attempting to improve the overall network cost. If the total cost cannot be further reduced as a result of the changes, the procedure is terminated.

Another related problem was also formulated by Efroyman and Ray (1966) as an integer programming problem and solved by the branch-bound method. The authors have also described in detail how the algorithm can be used to solve settlement problems involving fixed and particularly linear variable costs.

Khumbala (1972) proposed more effective branching rules for the branch-bound algorithm and improved the efficiency of the solution. These branching rules have been tested with reductions in calculation times and stocking requirements.

Erlenkotter (1978) proposed the well-known DUALOC procedure to find optimal solutions to the problem of interest. DUALOC, as its name implies, is a dual-based solution procedure. The procedure starts with any dual possible solution, continuing the multiplier to the point where it is not possible to further reduce the complementary slackness violation at each step, at the last step. The DUALOC procedure produces dual solutions, which are often the optimal solution to the primal problem. If the optimal solution cannot be achieved as a result of said procedure, the process is completed using the branch-bound procedure.

Pirkul and Schilling (1991) developed the maximum coverage problem by including the capacity constraints of the facilities. The problem has been solved by using the Lagranj Relaxation method by loosening the demand assignment constant, and with possible input solutions for sub-problems. A heuristic method is used these input solutions in the lower gradient optimization procedure until the best solution was reached.

One of the earliest studies on the placement of warehouses was done by O’Kelly (1986). In this study, it has been proved that the single warehouse settlement problem is equal to the

Weber's minimum cost settlement model and the two warehouse settlements that can interact with each other are discussed with the help of relative positions and weight model.

O'Kelly (1987) modeled the warehouse layout problem with the second order integer programming formulation and proposed two heuristic methods. These intuitive methods assigns each request to the nearest first or the second warehouse.

Unlike O'Kelly (1987), Klincewicz (1991) proposed an intuitive method using a multi-criteria distance and flow-based assignment procedure, rather than assigning requests to warehouses based on distance alone. Klincewicz (1992) and Skorin-Kapov and Skorin-Kapov (1994) addressed the warehouse settlement problem as two problems as placement and routing and tried to find successful results for sub-problems by using taboo research.

Atkinson (2002) considers transportation as the most important criteria in positioning of plants. His study includes proximity to customers, cost, current labor quality and its cost, costs of real estate, taxes and incentives as citeria.

Avittathur et al. (2005) developed a model for an India case that storing products in warehouses in a way that minimizes the sales tax collected by the state from interstate sales transactions. When analyzing the locations of the warehouses, fixed investment and transportation costs, product range, distribution function on demand points and level of service, current tax rates were used. Using an approximate integer programming technique instead of standard non-linear hash integer programming, an optimal solution was found for the manufacturer's distribution network.

Chen (2001) dealt with the linguistic evaluation and weights proposed by the fuzzy set theory, warehouse location selection, investment cost, expansion opportunities, availability of inputs, availability of human resources and proximity to the market.

Hajiaghaei-keshteli and Sajadifar (2010) proposed a three-stage inventory system with two warehouses to serve N customers, and the cost function for this three-stage supply chain was introduced. The model discussed in this study differs from the previously discussed models in terms of the number of stages. Namely, the number of stages analyzed is increased from two to three.

Ko (2005) proposed an integrated decision model based on decision factors analysis and analytic hierarchy process in determining the locations of the warehouses. With the survey applied to one hundred and eighty managers in the sector, twenty decision factors under the five main decision groups and their weighted values were calculated.

Karabakal et al. (2000) used simulation and mixed integer programming models together to determine the place and number of automobile processing and warehouses and used in determining the series of demand markets that each center responded to. While customer demands, customer preferences and delays during transportation are accepted as stochastic, relative costs and level of service to customers were evaluated together. The proposed model was applied to Volkswagen America's supply chain.

Different from the existing works, in this thesis we implement a transportation model with warehouse opening decisions for a fish feed company in Turkey. First, potential locations in Turkey regions are determined by a heuristic approach. Second, demands are estimated in those regions. Third, different scenarios are developed based-on capacities of warehouses. Last, optimal solutions assigning customers for the opened warehouses are determined by the well-known transportation model (Chopra and Meindl, 2013). The results are compared for each scenario and the best ones are suggested based on those scenarios.

CHAPTER 3
PROBLEM DEFINITION and IMPLEMENTATION

3.1. Problem Definition for Fish Feed Company

The studied fish feed company is located in Bodrum, Muğla. It already has shipments from factory to customers directly. The company doesn't have any warehouse or distributor in Turkey. The company management wants to solve an optimal warehouse location problem for its customers. The motivation of this thesis is developed on that target. In the warehouse location problem, it is required to decrease the total transportation cost. The related data, the logistic costs, rental warehouse offers for in different locations, demands based on every city or smaller parts, capacity of production to determine warehouse capacities, etc. were obtained from the related departments. After the calculations and discussion with the management, four city groups are defined to be considered for the location of the warehouses. The details are explained in Section 3.3.1.

3.2. Mathematical Model for the Problem

Solution approach

A general mathematical model for a capaciated plant location problem formulated By Balinski (1965) and already provided in Chopra and Meindl (2013).

This model is summarized as in below:

Parameters:

n : Number of potential warehouse locations
m : Number of customers (demand points)
D_j : Annual demand of customer j
f_i : Annual fixed cost of keeping warehouse i open
c_{ij} : Transportation cost from warehouse i to customer j
Cap_i : Capacity of warehouse i

Decision Variables

$y_i = 1$ if warehouse i is open, 0 otherwise
$x_{ij} =$ quantity transported from warehouse i to customer j

Objective function:

$$Minimize \sum_{i=1}^{n} f_i y_i + \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij} x_{ij} \qquad (1)$$

The objective function minimizes addition of annual fixed cost of keeping warehouse if this warehouse is opened and plus the transportation cost from warehouse to customer.

Subject to

Constraint 1

$$\sum_{i=1}^{n} x_{ij} = D_j \qquad \forall j \qquad (2)$$

This constraint shows that the total transported volume should be equal to customer demand. It aims to meet the total demand of customers.

Constraint 2

$$\sum_{j=1}^{m} x_{ij} \le Cap_i y_i \qquad \forall i \qquad (3)$$

This constraint satisfies that the total transported volume from warehouse cannot be higher than the total capacity of the warehouse, i.

Constraint 3

$$y_i \in \{0,1\} \qquad \forall i \qquad (4)$$

This constraint assigns a warehouse's opening decision as binary variable, "0" or "1".

Constraint 4

$x_{ij} \in Z^{+} \cup \{0\} \qquad \forall i, j \qquad\qquad (5)$

This constraint provides that the transported volume from warehouse i to customer j and should be a positive number.

According to our study the specific values are set as in below:

Parameters:

n = 4 potential warehouses

m = 10 customers (demand points)

j = 1, 2, … , 10.

Dj:

- $D1$: 10,803 tons (35%)
- $D2$: 7,084 tons (23%)
- $D3$: 386 tons (1%)
- $D4$: 1,736 tons (6%)
- $D5$:197 tons (1%)
- $D6$:1,234 tons (4%)
- $D7$:8,307 tons (27%)
- $D8$: 79 tons (1%)
- $D9$:365 tons (1%)
- $D10$: 229 tons (1%)

The precantage values in demand values show the ratio of demand of customer j.

Decision Variables

$y_i = 1$ if warehouse i is open, 0 otherwise

$x_{ij} =$ quantity transported from warehouse i to customer j

Objective Function

$$Minimize \sum_{i=1}^{n} f_i y_i + \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} x_{ij}$$

$$Minimize \quad f_1y_1 + f_2y_2 + f_3y_3 + f_4y_4 + \sum_{i=1}^{4} (c_{i1}x_{i1} + c_{i2}x_{i2} + c_{i3}x_{i3} + c_{i4}x_{i5} + \ldots \ldots .. c_{i10}x_{i10})$$

$$+(\boldsymbol{c_{11}x_{11} + c_{12}x_{12} + c_{13}x_{13} + c_{14}x_{14} + \cdots \ldots . c_{110}x_{110}})$$

$$+(\boldsymbol{c_{21}x_{21} + c_{22}x_{22} + c_{23}x_{23} + c_{24}x_{24} + \cdots \ldots . c_{210}x_{210}})$$

$$+(\boldsymbol{c_{31}x_{31} + c_{32}x_{32} + c_{33}x_{33} + c_{34}x_{34} + \cdots \ldots . c_{310}x_{310}})$$

$$+(\boldsymbol{c_{41}x_{41} + c_{42}x_{42} + c_{43}x_{43} + c_{44}x_{44} + \cdots \ldots . c_{410}x_{410}})$$

Constraint 1 $\sum_{i=1}^{n} x_{ij} = D_j \quad \forall j$

Constraint 2 $\sum_{j=1}^{m} x_{ij} \le Cap_i y_i \quad \forall i$

Constraint 3 $y_i \in \{0,1\} \quad \forall i$

Constraint 4 $x_{ij} \in Z^+ \cup \{0\} \quad \forall i, j$

Constraint 1

$$\sum_{i=1}^{n} x_{ij} = D_j \quad \forall j$$

Constraint 2

$$\sum_{j=1}^{m} x_{ij} \le Cap_i y_i \quad \forall i$$

Constraint 3

$$y_i \in \{0,1\} \quad \forall i$$

Constraint 4

$$x_{ij} \in Z^+ \cup \{0\} \quad \forall i, j$$

3.3. Implementattion CPLEX for Several Scenerios

The mathematical model is solved by using CPLEX and run for many variations. All the models are structed based on the objective function and contraints given in Section 3.2. Table 1 shows the customers demands (in tonnes) and their locations. According to that there are ten different groups around the country. These groups are also shown on the Turkey's map in Figure 4.

Table 1: Customer locations and their demands

Region NO	Region name	Total Demand (%)	Total Demand (Tonnes)
1	Bodrum	36	10,803
2	İzmir	23	7,084
3	Afyon	1	386
4	Isparta	6	1,736
5	Düzce	1	197
6	Maraş	4	1,234
7	Trabzon	27	8,307
8	Mardin	0	79
9	Elazığ	1	365
10	Van	1	229
		100%	

In Figure 4, note that there is a location shown by a star sign. That location is the Bodrum location where the company's main warehouse is already located there. Hence, this warehouse is considered to be open in all the tried scenarios.

Figure 4: Turkey's map and the locations of the customers on the map

3.3.1. Four Warehouse Combinations with Different Locations

After the demand regions are determined; we define four city groups as in below for the warehouse scenarios. Namely, in each group it is assummed that there are upto four warehouses to open. These groups are created by considering demand locations and already the open warehouse in Bodrum.

1. A Group: İzmir, Bodrum, Konya, Trabzon
2. B Group: İzmir, Bodrum, Elazığ, Trabzon
3. C Group: Afyon, Bodrum, Elazığ, Trabzon
4. D Group: Afyon, Bodrum, Kahramanmaraş, Trabzon

According to the potential warehouse locations, warehouse to customer distances and their transportation costs, are prepared in Table 2 and Table 3, respectively. These are prepared by the help of the logistics department. Table 2 shows the distance between warehouses to customers. Table 3 shows transportation cost of per ton from warehouse to customer. In creating those groups, it is cared that there will be a single specific city in each group. Also, as mentioned previously, because it is already an existing warehouse, the Bodrum warehouse is always included in each group. Hence, its opening cost is assummed to be zero in the models. However, when we run the scenarios, in some cases, this warehouse's capacity is assumed to be zero, to consider that what happens if the management wants to close it in a future plan.

The whole considered scenarios are summarized in Table 4. According to that, there are fifty two scenarios. Note that these scenarios are developed based on different capacity scenarios. We optimize each scenario and compare the results based on the objective function values. Also note that since it is already open, the binary value "1" is already assigned for all the Bodrum warehouses in Table 4.

Table 2: Distance between warehouses and customers

		CUSTOMERS									
		Bodrum	İzmir	Afyon	Isparta	Düzce	K.maraş	Trabzon	Mardin	Elazığ	Van
WAREHOUSES	İzmir	180 km	0 km	365 km	395 km	580 km	1090 km	1415 km	1445 km	1285 km	1780 km
	Bodrum	0 km	180 km	455 km	380 km	795 km	1155 km	1440 km	1510 km	1355 km	1845 km
	Konya	620 km	560 km	230 km	240 km	540 km	535 km	890 km	890 km	745 km	1220 km
	Trabzon	1440 km	1415 km	1005 km	1130 km	850 km	720 km	0 km	665 km	465 km	640 km
	Elazığ	1355 km	1285 km	950 km	990 km	985 km	320 km	465 km	250 km	0 km	470 km
	Afyon	455 km	365 km	0 km	165 km	530 km	755 km	1005 km	1115 km	950 km	1445 km
	K.maraş	1155 km	1090 km	755 km	775 km	815 km	0 km	720 km	545 km	320 km	745 km

Table 3: Transportation costs between warehouses and customers

		CUSTOMERS									
		Bodrum	İzmir	Afyon	Isparta	Düzce	K.maraş	Trabzon	Mardin	Elazığ	Van
WAREHOUSES	İzmir	132 tl/ton	0 tl/ton	131 tl/ton	146 tl/ton	161 tl/ton	211 tl/ton	236 tl/ton	246 tl/ton	266 tl/ton	276 tl/ton
	Bodrum	0 tl/ton	66 tl/ton	75 tl/ton	95 tl/ton	110 tl/ton	160 tl/ton	185 tl/ton	195 tl/ton	210 tl/ton	220 tl/ton
	Konya	211 tl/ton	275 tl/ton	180 tl/ton	185 tl/ton	265 tl/ton	0 tl/ton	255 tl/ton	245 tl/ton	295 tl/ton	315 tl/ton
	Trabzon	368 tl/ton	350 tl/ton	305 tl/ton	315 tl/ton	315 tl/ton	275 tl/ton	0 tl/ton	315 tl/ton	265 tl/ton	285 tl/ton
	Elazığ	420 tl/ton	400 tl/ton	330 tl/ton	385 tl/ton	400 tl/ton	290 tl/ton	330 tl/ton	290 tl/ton	210 tl/ton	310 tl/ton
	Afyon	150 tl/ton	140 tl/ton	75 tl/ton	135 tl/ton	175 tl/ton	245 tl/ton	250 tl/ton	275 tl/ton	250 tl/ton	305 tl/ton
	K.maraş	320 tl/ton	300 tl/ton	250 tl/ton	245 tl/ton	325 tl/ton	160 tl/ton	275 tl/ton	255 tl/ton	235 tl/ton	305 tl/ton

Table 4: The considered scenarios in the optimization model

Scenario #	Group of cities	Warehouse locations	Capacities (tonnes)	Opening Decision (0/1)	WH #
1	*A*	**İzmir**	100	0	1
		Bodrum	100	1	
		Konya	100	0	
		Trabzon	100	0	
2	*B*	**İzmir**	100	0	1
		Bodrum	100	1	
		Elazığ	100	0	
		Trabzon	100	0	
3	*C*	**Afyon**	100	0	1
		Bodrum	100	1	
		Elazığ	100	0	
		Trabzon	100	0	
4	*D*	**Afyon**	100	0	1
		Bodrum	100	1	
		Kahramanmaraş	100	0	
		Trabzon	100	0	
5	*A*	**İzmir**	100	0	2
		Bodrum	75	1	
		Konya	150	0	
		Trabzon	75	1	

6	***B***	**İzmir**	50	0	2
		Bodrum	75	1	
		Elazığ	200	0	
		Trabzon	50	1	
7	***C***	**Afyon**	150	0	2
		Bodrum	75	1	
		Elazığ	50	1	
		Trabzon	150	0	
8	***D***	**Afyon**	50	0	2
		Bodrum	75	1	
		Kahramanmaraş	200	0	
		Trabzon	50	1	
9	***A***	**İzmir**	75	0	1
		Bodrum	125	1	
		Konya	75	0	
		Trabzon	125	0	
10	***B***	**İzmir**	125	0	2
		Bodrum	75	1	
		Elazığ	100	0	
		Trabzon	75	1	
11	***C***	**Afyon**	300	0	1
		Bodrum	300	1	
		Elazığ	300	0	
		Trabzon	300	0	
12	***D***	**Afyon**	50	1	2
		Bodrum	75	1	
		Kahramanmaraş	50	0	
		Trabzon	200	0	
13	***A***	**İzmir**	100	0	2
		Bodrum	75	1	
		Konya	100	1	
		Trabzon	200	0	
14	***B***	**İzmir**	100	0	1
		Bodrum	110	1	
		Elazığ	100	0	
		Trabzon	100	0	
15	***C***	**Afyon**	100	0	1
		Bodrum	110	1	
		Elazığ	100	0	
		Trabzon	100	0	

16	***D***	**Afyon** **Bodrum** **Kahramanmaraş** **Trabzon**	100 106 100 100	0 1 0 0	1
17	***A***	**İzmir** **Bodrum** **Konya** **Trabzon**	200 60 100 100	0 1 1 0	2
18	***B***	**İzmir** **Bodrum** **Elazığ** **Trabzon**	100 0 100 100	0 0 1 1	2
19	***C***	**Afyon** **Bodrum** **Elazığ** **Trabzon**	50 50 50 50	0 1 1 1	3
20	***D***	**Afyon** **Bodrum** **Kahramanmaraş** **Trabzon**	100 0 100 100	1 0 0 1	2
21	***A***	**İzmir** **Bodrum** **Konya** **Trabzon**	100 50 200 100	0 1 0 1	2
22	***B***	**İzmir** **Bodrum** **Elazığ** **Trabzon**	100 50 100 50	0 1 1 0	2
23	***C***	**Afyon** **Bodrum** **Elazığ** **Trabzon**	75 50 75 50	0 1 1 1	3
24	***D***	**Afyon** **Bodrum** **Kahramanmaraş** **Trabzon**	200 50 200 100	0 1 0 1	2
25	***A***	**İzmir** **Bodrum** **Konya** **Trabzon**	100 200 100 100	0 1 0 0	1

26	***B***	**İzmir**	50	0	3
		Bodrum	50	1	
		Elazığ	50	1	
		Trabzon	50	1	
27	***C***	**Afyon**	75	0	2
		Bodrum	75	1	
		Elazığ	75	1	
		Trabzon	100	0	
28	***D***	**Afyon**	25	1	4
		Bodrum	25	1	
		Kahramanmaraş	25	1	
		Trabzon	25	1	
29	***A***	**İzmir**	80	0	2
		Bodrum	80	1	
		Konya	80	1	
		Trabzon	80	0	
30	***B***	**İzmir**	25	0	2
		Bodrum	75	1	
		Elazığ	25	1	
		Trabzon	100	0	
31	***C***	**Afyon**	75	0	2
		Bodrum	100	1	
		Elazığ	100	0	
		Trabzon	75	1	
32	***D***	**Afyon**	100	0	2
		Bodrum	75	1	
		Kahramanmaraş	106	0	
		Trabzon	100	1	
33	***A***	**İzmir**	100	0	1
		Bodrum	125	1	
		Konya	100	0	
		Trabzon	100	0	
34	***B***	**İzmir**	100	0	1
		Bodrum	25	1	
		Elazığ	100	1	
		Trabzon	25	0	
35	***C***	**Afyon**	10	0	2
		Bodrum	90	1	
		Elazığ	10	0	
		Trabzon	10	1	

36	***D***	**Afyon**	100	0	1
		Bodrum	100	1	
		Kahramanmaraş	100	0	
		Trabzon	100	0	
37	***A***	**İzmir**	100	0	1
		Bodrum	110	1	
		Konya	100	0	
		Trabzon	100	0	
38	***B***	**İzmir**	100	0	2
		Bodrum	75	1	
		Elazığ	25	0	
		Trabzon	25	1	
39	***C***	**Afyon**	150	0	2
		Bodrum	75	1	
		Elazığ	150	0	
		Trabzon	100	1	
40	***D***	**Afyon**	25	1	4
		Bodrum	25	1	
		Kahramanmaraş	25	1	
		Trabzon	25	1	
41	***A***	**İzmir**	101	0	1
		Bodrum	101	1	
		Konya	101	0	
		Trabzon	101	0	
42	***B***	**İzmir**	25	0	2
		Bodrum	75	1	
		Elazığ	100	0	
		Trabzon	25	1	
43	***C***	**Afyon**	100	0	2
		Bodrum	75	1	
		Elazığ	100	1	
		Trabzon	105	0	
44	***D***	**Afyon**	35	1	3
		Bodrum	0	0	
		Kahramanmaraş	35	1	
		Trabzon	3	1	

45	*A*	**İzmir** **Bodrum** **Konya** **Trabzon**	101 75 101 101	0 1 1 0	2
46	*B*	**İzmir** **Bodrum** **Elazığ** **Trabzon**	100 25 25 100	0 1 0 1	2
47	*C*	**Afyon** **Bodrum** **Elazığ** **Trabzon**	100 108 100 100	0 1 0 0	1
48	*D*	**Afyon** **Bodrum** **Kahramanmaraş** **Trabzon**	50 50 50 50	0 1 0 1	2
49	*A*	**İzmir** **Bodrum** **Konya** **Trabzon**	100 50 100 100	0 1 1 0	2
50	*B*	**İzmir** **Bodrum** **Elazığ** **Trabzon**	75 75 75 75	0 1 0 1	2
51	*C*	**Afyon** **Bodrum** **Elazığ** **Trabzon**	50 100 50 50	0 1 0 0	1
52	*D*	**Afyon** **Bodrum** **Kahramanmaraş** **Trabzon**	30 0 30 10	0 0 0 1	1

3.3.2. Optimization Results Based-on Warehouse Combinations and City Groups

As mentioned previously, four city groups are determined and shown as A, B, C, D in Table 4. The capacities are changed for these groups and the optimization model is run in CPLEX for each. The results are summarized based on these city groups and the results are commented by considering several way of comparisons in the below sub-sections.

3.3.2.1 City Group *A*

The optimization results are summarized in Table 5 for city group *A*. According to that the best result is obtained at the 8,740 TL cost level for a single scenario option based-on the city combinations. The result suggests to consider just the Bodrum warehouse.

Table 5: Optimization results for City Group *A*

Scenario #	Group of cities	Warehouse locations	Capacities (tonnes)	Total Cost (TL)	Opening Decision (0/1)	Opening WH decision #
1	***A***	**İzmir Bodrum Konya Trabzon**	100 100 100 100	8,740	0 1 0 0	1
5			100 75 150 75	105,474	0 1 0 1	2
9			75 125 75 125	8,740	0 1 0 0	1
13			100 75 100 200	133,479	0 1 1 0	2
17			200 60 100 100	133,479	0 1 1 0	2

21			100 50 200 100	139,049	0 1 0 1	2
25			100 200 100 100	8,740	0 1 0 0	1
29			80 80 80 80	110,229	0 1 1 0	2
33			100 125 100 100	8,740	0 1 0 0	1
37			100 110 100 100	8,740	0 1 0 0	1
41			101 101 101 101	8,740	0 1 0 0	1
45			101 75 101 101	133,429	0 1 1 0	2
49			100 50 100 100	133,429	0 1 1 0	2

Results:

The minimum cost (TL): 8,740
Number of best scenerios: 1, 9, 33, 37, 41
Logical action to take: to continue with fixed warehouse

3.3.2.2 City Group *B*

The optimization results are summarized in Table 6 for city group *B*. According to that the best result is obtained at the 8,740 TL again. The optimal result suggests to consider just the Bodrum warehouse again.

Table 6: Optimization results for City Group *B*

Scenario #	Group of cities	Warehouse locations	Capacities (tonnes)	Total Cost (TL)	Opening Decision (0/1)	Opening WH decision #
2	*B*	İzmir Bodrum Elazığ Trabzon	100 100 100 100	8,740	0 1 0 0	1
6			50 75 200 50	71,549	0 1 0 1	2
10			125 75 100 75	105,299	0 1 0 1	2
14			100 110 100 100	8,740	0 1 0 0	1
18			100 0 100 100	248,128	0 0 1 1	2
22			100 50 100 50	140,004	0 1 1 0	2
26			50 50 50 50	120,279	0 1 1 1	3

30			25	39,674	0	2
			75		1	
			25		1	
			100		0	
34			100	149,300	0	1
			25		1	
			100		1	
			25		0	
38			100	29,916	0	2
			75		1	
			25		0	
			25		1	
42			25	29,916	0	2
			75		1	
			100		0	
			25		1	
46			100	119,018	0	2
			25		1	
			25		0	
			100		1	
50			75	79,986.5	0	2
			75		1	
			75		0	
			75		1	

Results:

The minimum cost (TL):	8,740
Number of best scenerios:	2, 14
Logical action to take:	to continue with fixed warehouse

3.3.2.3 City Group *C*

The optimization results are summarized in Table 7 for city group C. According to that the best result is obtained at the 8,740 TL again. The optimal result suggests to consider just the Bodrum warehouse again.

Table 7: Optimization results for City Group *C*

Scenario #	Group of cities	Warehouse locations	Capacities (tonnes)	Total Cost (TL)	Opening Decision (0/1)	Opening WH decision #
3	*C*	Afyon Bodrum Elazığ Trabzon	100 100 100 100	8,740	0 1 0 0	1
7	*C*	Afyon Bodrum Elazığ Trabzon	150 75 50 150	69,890	0 1 1 0	2
11	*C*	Afyon Bodrum Elazığ Trabzon	300 300 300 300	8,740	0 1 0 0	1
15	*C*	Afyon Bodrum Elazığ Trabzon	100 110 100 100	8,740	0 1 0 0	1
19	*C*	Afyon Bodrum Elazığ Trabzon	50 50 50 50	137,280	0 1 1 1	3
23	*C*	Afyon Bodrum Elazığ Trabzon	75 50 75 50	137,280	0 1 1 1	3
27	*C*	Afyon Bodrum Elazığ Trabzon	75 75 75 100	99,890	0 1 1 0	2

31			75 100 100 75	101,515	0 1 0 1	2
35			10 90 10 10	21,095	0 1 0 1	2
39			150 75 150 100	139,265	0 1 0 1	2
43			100 75 100 105	129,445	0 1 1 0	2
47			100 108 100 100	8,740	0 1 0 0	1
51			50 100 50 50	8,740	0 1 0 0	1

Results:

The minimum cost (TL):	8,740
Number of best scenerios:	3, 11, 47, 51
Logical action to take:	to continue with fixed warehouse

3.3.2.4 City Group *D*

The optimization results are summarized in Table 8 for city group *D*. According to that the best result is obtained at the 8,740 TL again. The optimal result suggests to consider just the Bodrum warehouse again.

Table 8: Optimization results for City Group *D*

Scenario #	Group of cities	Warehouse locations	Capacities (tonnes)	Total Cost (TL)	Opening Decision (0/1)	Opening WH decision #
4	*D*	Afyon Bodrum Kahramanmaraş Trabzon	100 100 100 100	8,740	0 1 0 0	1
8			50 75 200 50	71,765	0 1 0 1	2
12			50 75 50 200	77,105	1 1 0 0	2
16			100 106 100 100	8,740	0 1 0 0	1
20			100 0 100 100	282,180	1 0 0 1	2
24			200 50 200 100	144,870	0 1 0 1	2
28			25 25 25 25	130,190	1 1 1 1	4
32			100 75 106 100	139,265	0 1 0 1	2

36			100	8,740	0	1
			100		1	
			100		0	
			100		0	
40			25	113,753.75	1	4
			25		1	
			25		1	
			25		1	
44			35	171,375	1	3
			0		0	
			35		1	
			35		1	
48			50	75,900	0	2
			50		1	
			50		0	
			50		1	
52			30	160,405	0	1
			0		0	
			30		0	
			100		1	

Best costs(TL): 8,740
Number of best scenerios: 4, 16, 36
Logical action to take: to continue with fixed warehouse

3.4. Comparing and reporting the best results to the management

According to that, both the optimal suggestions as well as if the fixed warehouse (i.e., the Bodrum warehouse) was not open, the alternative solutions without the Bodrum warehouse were also provided in the last row. These alternative solutions are suggested based on the second best results in the Tables of 5-8.

Table 9: The suggested results by using the optimal solutions

	city group *A*	city group *B*	city group *C*	city group *D*
The minimum cost (TL)	8,740	8,740	8,740	8,740
Number of best scenerios:	1, 9, 33, 37, 41	2, 14	3, 11, 47, 51	4, 16, 36
Logical action to take:	to continue with fixed warehouse	to continue with fixed warehouse	to continue with fixed warehouse	to continue with fixed warehouse
Most offered city except the fixed WH:	Konya	Trabzon	Trabzon, Elazığ	Trabzon

Accroding to Table 9, in city groups *A*, if the Bodrum warehouse is ignored, the best solution suggests to open the warehouse in Konya. For city groups *B*, it suggests the to open it in Trabzon. For city groups C, it suggests to open the warehouse both in Trabzon and Elazığ, and last in city groups D, the result suggests to open the warehouse in Trabzon.

CHAPTER 4
CONCLUSION

In the recent incerasing competition among companies, the companies tend to make a difference in their supply chain strategies by decreasing response time in delivery of products for their customers. The customers are asking for a better service and to have the product as quick as possible has the primary importance. The factories has to organize their supply chain networks with this goal while keeping their opeartional costs at minimum. This thesis studies such a case study for a fish feed company in Turkey. Specifically, in this thesis, it is studied whether to open one or more temporary warehouses for the company in distributing their product to customers. For that four-alternative city groups are developed for different warehouse capacities. The optimization model is develeoped on a transaportation model. The models are solved for fifty two different scenarios scenarios by using CPLEX. The results suggest to work with the existing warehouse due to not having an opening fixed cost.

However, alternatively, if the company does close the Bodrum warehouse, the alternative solution are also given in the study. For sure in real life there are many other parameters to be concerned during decision making but for the sake of simplicity and to see the effectiveness of the method many parameters are taken as constant. As a future work, one may include more alternative scenarios in the evaluation process.

REFERENCES

Avittathur, B., Shah, J. ve Gupta, O.K. (2005), “Distribution Centre Location Modeling for Differential Sales Tax Structure”, European Journal of Operational Research, 162: 191-205.

Ballinski, M.L. (1965), “Integer Programming: Methods, Uses, Computation”, Management Science, 12: 255-313.

Ballou, R.H. (1999), Business Logistics Management, 4th edition, Prentice Hall, 12, New Jersey.

Chen, C.T. (2001), “A Fuzzy Approach to Select the Location of the Distribution Center”, Fuzzy Sets and Systems, 118: 65-73.

Deloitte Global (2003), “Mastering Complexity in Global Manufaturing: Powering Profits and Growth Through Value Chain Synchronization”, Deloitte Global Manufacturing Study.

Hajiaghaei-keshteli M. ve Sajadifar S.M. (2010), “Deriving the Cost Function for a Class of Three-Echelon Inventory System with N-retailers and One-for-one Ordering Policy”, The International Journal of Advanced Manufacturing Technology, 50:343–351.

Karabakal N., Gunal A. ve Ritchie W. (2000), “Supply-chain analysis at Volkswagen of America”, Interfaces, 30(4): 46–55.

Klincewicz, J.G. (1991), “Heuristics for the p-Hub Location Problem”, European Journal of Operational Research, 53: 25-37.

Klincewicz, J.G. (1992), “Avoiding Local Optima in the p-Hub Location Problem Using Tabu Search and GRASP”, Annals of OperationS Reseach, 40: 283-302.

Klincewicz, J.G. (2002), “Enumeration and Search Procedures for a Hub Location Problem with Economies of Scale”, Annals of OperationS Reseach, 110: 107-122.

Ko, J., (2005), “Solving a Distribution Facility Location Problem Using an Analytic Hierarchy Process Approach”, Proceedings 0f the 8th International Symposium on the Analytic Hierarchy Process, 8-10 July. 2005, Honolulu, Hawaii.

Kuehn, A.A. ve Hamburger, M. J. (1963), “A Heuristic Program for Locating Warehouses”, Management Science, 9 (4): 643-666.

O’Kelly, M.E. (1986), “The Location of Interacting Hub Facilities”, Transportation Science, 20(2): 92-106.

Peidro D., Mula J., Poler R. vd. (2009), "Quantitative Models for Supply Chain Planning under Uncertainty: a Review", International Journal of Advanced Manufacturing Technology, 43: 400–420.

Pirkul, H. ve Schilling, D.A. (1991), "The Maximal Covering Location Problem with Capacities on Total Workload", Management Science, 37(12): 238-248.

Sunil Chopra, Peter Meindl (2013) "Supply Chain Management Strategy, Planning, and Operation-Pearsons"

Thomas, D.J ve Griffin, P.M. (1996), "Coordinated Supply Chain Management", European Journal of Operational Research, 94: 1-15.

APPENDIX 1

OPL CODES

```
MOD
int NbCustomers=...;
int NbWarehouses=...;
range Customer=1..NbCustomers;
range Warehouse=1..NbWarehouses;
float D[Customer]=...; //annual customer demand
float f[Warehouse]=...; //fixed cost
float c[Warehouse][Customer]=...; //transportation cost
int Cap[Warehouse]=...; //warehouse capacity

//Decision Variables
dvar boolean y[Warehouse];
dvar int+ X[Warehouse][Customer];

//Objective Function
minimize sum(i in Warehouse)(f[i]*y[i])+sum(i in Warehouse, j in
Customer)(c[i][j]*X[i][j]);

subject to{

//demand satisfaction constraint
c1:
forall(j in Customer)
sum (i in Warehouse)X[i][j]>=D[j];

//Warehouse capacity constraint
c2:
forall(i in Warehouse)
sum (j in Customer)X[i][j]<=Cap[i]*y[i];

}
DAT

SheetConnection NbofCust ("TezData.xlsx");
NbCustomers from SheetRead (NbofCust, "'data'!B32");

SheetConnection NbofWH ("TezData.xlsx");
NbWarehouses from SheetRead (NbofCust, "'data'!B33");

SheetConnection Demand ("TezData.xlsx");
D from SheetRead (Demand, "data!$C$36:$C$45");

SheetConnection FixedCost ("TezData.xlsx");
f from SheetRead (FixedCost, "data!$D$24:$D$27");

SheetConnection TSCost ("TezData.xlsx");
c from SheetRead (TSCost, "data!$C$16:$L$19");

SheetConnection Capacity ("TezData.xlsx");
Cap from SheetRead (Capacity, "data!$C$24:$C$27");
```