AN ANALYTICAL METHOD
FOR WAREHOUSE SELECTION
IN AN INTERMODAL TRANSPORTATION NETWORK

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Thesis for the Master's Program in Logistics Management

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ETHICAL DECLARATION

I hereby declare that I am the sole author of this thesis and that I have conducted my work in accordance with academic rules and ethical behaviour at every stage from the planning of the thesis to its defence. I confirm that I have cited all ideas, information and findings that are not specific to my study, as required by the code of ethical behaviour, and that all statements not cited are my own.

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ABSTRACT

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Master's Program in Logistic Management

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In this thesis, we consider a company that provides partial and full-load transportation services between Türkiye and Germany. The company carries out intermodal transportation and aims to use contracted intermediary warehouses in Germany for final deliveries of some loads to reduce costs. This study aims to determine the best subset of warehouses among alternative ones. To achieve this goal, we develop a mixed integer mathematical programming model. This model determines warehouse opening decisions, usage amounts of different transportation modes, flows between modes and opened warehouses, and the method used for the final delivery. The purpose of the model is to minimize the total transportation and warehouse fixed costs. We used randomly generated data sets, and perform sensitivity analysis on cost, demand and capacity values. Our computational results showed that the optimal warehouse location decisions are robust to changes in several cost parameters.

Keywords: Facility Location Problem, Intermodal Transportation, Mathematical Modeling, Sensitivity Analysis.

ÖZET

İNTERMODAL TAŞIMACILIK AĞINDA DEPO SEÇİMİ İÇİN ANALİTİK BİR YÖNTEM

Türkmenoğlu Duman, İrem

Lojistik Yönetimi Yüksek Lisans Programı

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Ekim, 2024

Bu tezde, Türkiye ile Almanya arasında parsiyel ve komple yük taşımacılığı hizmeti veren bir firmayı ele alıyoruz. Firma intermodal taşımacılık yapmakta ve maliyetlerini azaltmak için çeşitli yükleri kendisi teslim etmek yerine Almanya'da anlaştığı aracı depoları kullanmayı hedeflemektedir. Çalışmanın amacı, bu hizmeti veren alternatif depolar arasından en uygun depo alt kümesinin belirlenmesidir. Bu amaca ulaşmak için bir karışık tamsayılı matematiksel programlama modeli geliştirdik. Bu model depo açma kararlarını, farklı taşıma modlarının kullanım miktarlarını, modlar ile açılan depolar arasındaki akışları ve son teslimat için kullanılan teslimat yöntemini belirlemektedir. Modelin amacı toplam taşıma ve depo anlaşma maliyetlerini en aza indirmektir. Rastgele oluşturulmuş veri setleri kullanarak maliyet, talep ve kapasite değerlerine ilişkin duyarlılık analizleri gerçekleştiriyoruz. Hesaplamalı sonuçlarımız, optimum depo yeri kararlarının çeşitli maliyet parametrelerindeki değişikliklere karşı dayanıklı olduğunu göstermektedir.

Anahtar Kelimeler: Tesis Yer Seçimi Problemi, Intermodal Taşımacılık, Matematiksel Modelleme, Duyarlılık Analizi.

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I would like to thank my father, Seçkin Duman; my mother, Feryal Duman; my sister, Beril Duman Silare; and my beloved husband, Yavuz Türkmenoğlu, whom I married during the process of writing my thesis, for their understanding and trust, for their unwavering support during my Master's education.

PREFACE

There was only one starting point for me wanting to have a Master's degree with a thesis. And that was to be able to benefit someone who reads it for any reason. Thus, I was inclined to choose a topic that was applicable. The research we have conducted consists of examples that are very close to real life. It addresses a real need within the industry. A literature review regarding warehouse selection may bring different perspectives to individuals.

İzmir

03.10.2024

İrem Duman Türkmenoğlu

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LIST OF ABBREVIATIONS

IFTNs: Intermodal freight transportation networks

TÜİK: Türkiye Statistical Institute

EOS: Economies of Scale

GE: General Electric

VRP: Vehicle Routing Problem

RO-RO: Roll On Roll Off

GAMS: General Algebraic Modeling System

FTL: Full Truck Load

GDP: Gross Domestic Product

LPI: Logistics Performance Index

TC: Transportation Cost

FC: Fixed Cost

CHAPTER 1: INTRODUCTION

Delivering products safely and on time throughout the supply chain has been of considerable significance since the concept of trade existed. Today, suppliers, manufacturers, distributors and retailers must constantly improve their logistics processes to meet the demand for faster and more cost-effective delivery of a broader range of products. In today's competitive business environment, companies are facing the strategic challenge of making effective and efficient decisions regarding the warehouse and management of their materials.

This thesis topic addresses an important and current problem from both academic and industrial perspectives. Warehouse location selection and intermodal transportation are among the most complex and costly components of logistics and supply chain management. Businesses have to determine the most suitable warehouse locations to meet customer demands on time and at a low cost. This process is critical in minimizing total operational costs and environmental impacts.

Supply chain is the name given to the network of managerial tasks in which the flow of materials and information is effectively ensured between suppliers, producers, distributors, retailers and consumers within the system where raw materials are transformed into products or services and delivered to the end user. The supply chain can also be defined as the creation of business models that increase customer satisfaction by integrating basic business processes such as design, planning, operation, control, and monitoring of operations in the most accurate way. Storage is the process of receiving products and loads from a certain point, keeping them for a while, and then preparing them to be transferred to the desired points (Ghiani, Laporte and Musmanno, 2016). As crucial as the continuation of production is for companies, the problem-free storage of final products is also important. Storage constitutes a vital component of the supply chain, and selecting the right warehouse locations along with efficient warehouse management is crucial for enhancing the competitive advantage of businesses Storage, which is an important part of logistics, is critical for both the company providing the service and the owner of the products. Products must be stacked correctly and stored successfully throughout their time in the warehouse, and the transfer must occur smoothly and on time. Warehousing services play an active role in the transfer and storage of products and goods

(Mohamud et al. 2023). However, the process of warehouse establishment demands strategic decision-making. Companies should carefully consider several business-related factors, including the warehouse location, geographical distribution of customer demands, and quantities. Warehousing services play a crucial part in the logistics industry. Systematic storage leads to a significant reduction in overall operational costs. Hence, the storage service provision holds great significance for manufacturers, distributors, and suppliers. If executed correctly, many institutions and individuals will experience positive effects (SAP 2022).

The trade volume between Türkiye and Germany causes the logistics and transportation activities between these two countries to have strategic importance. As Figure 1 shows, Germany has the highest share of exports from Türkiye. USA ranks second in exports with Türkiye. UK is in third place, Italy is in fourth place and Iraq is in fifth place.

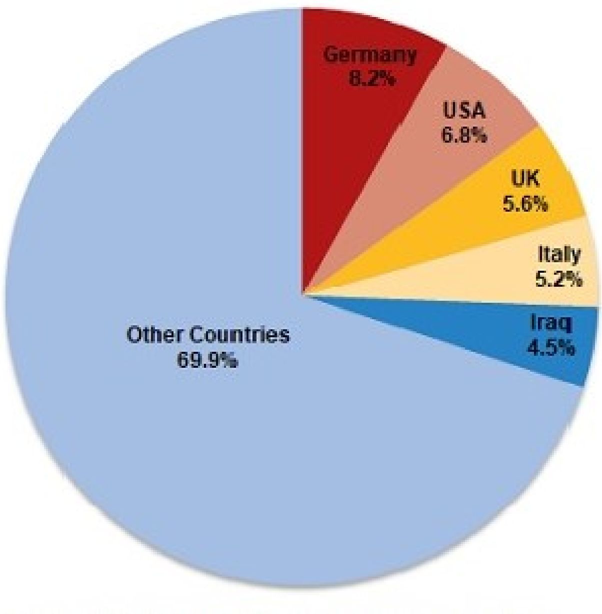


Figure 1. Exports By Countries, June 2024 (TÜİK, 2024)

In June 2024, the main partner country for exports was Germany with 1 billion 555 million dollars. In January-June 2024 period, the main partner country for exports was Germany with 10 billion 201 million dollars. The ratio of the first five countries in total exports was 29.8% in January-June 2024 (TÜİK 2024).

Another reason for intermodal transportation from Türkiye to Germany and opening a warehouse is the high Logistics Performance Index (LPI) score.

The logistics performance index reports of the World Bank organization attracted our attention. We made comparisons for Germany in previous years and other countries around it. 6 basic dimensions are taken as basis for the international score.

The logistics performance (LPI) is the weighted average of the country scores on the six key dimensions:

1) Efficiency of the clearance process (i.e., speed, simplicity and predictability of formalities) by border control agencies, including customs;

2) Quality of trade and transport related infrastructure (e.g., ports, railroads, roads, information technology);

3) Ease of arranging competitively priced shipments;

4) Competence and quality of logistics services (e.g., transport operators, customs brokers);

5) Ability to track and trace consignments;

6) Timeliness of shipments in reaching destination within the scheduled or expected delivery time.

Table 1. Comparison of Germany over the years according to LPI score (Logistic Performance Index, The World Bank 2023)

Year	LPI Score	Customs Score	Infrastructure Score	International shipments Score	Logistics competence Score	Tracking & tracing Score	Timelines Score
2010	**4.11**	4	4.34	3.66	4.14	4.18	4.48
2012	**4.03**	3.87	4.26	3.67	4.09	4.05	4.32
2014	**4.12**	4.1	4.32	3.74	4.12	4.17	4.36
2016	**4.23**	4.12	4.44	3.86	4.28	4.27	4.45
2018	**4.2**	4.09	4.37	3.86	4.31	4.24	4.39
2023	**4.1**	3.9	4.3	3.7	4.2	4.2	4.1

The second column of is included in the LPS score. There is customers score in the third column, infrastructure score in the fourth column, international shipments score in the fifth column, logistics competence score in the sixth column, tracking & tracing score in the seventh column and timeliness score in the eighth column.

Table 2. Compare countries and region LPI score (Logistic Performance Index, The World Bank 2023)

Country	Year	LPI Score	Customs Score	Infrastructure Score	International shipments Score	Logistics competence Score	Tracking & tracing Score	Timeliness Score
Albania	2023	2.5	2.4	2.7	2.8	2.3	2.3	2.5
Belgium	2023	4	3.9	4.1	3.8	4.2	4	4.2
Croatia	2023	3.3	3	3	3.6	3.4	3.4	3.2
France	2023	3.9	3.7	3.8	3.7	3.8	4	4.1
Georgia	2023	2.7	2.6	2.3	2.7	2.6	2.8	3.1
Germany	2023	4.1	3.9	4.3	3.7	4.2	4.2	4.1
Greece	2023	3.7	3.2	3.7	3.8	3.8	3.9	3.9
Hungary	2023	3.2	2.7	3.1	3.4	3.1	3.4	3.6
Italy	2023	3.7	3.4	3.8	3.4	3.8	3.9	3.9
Latvia	2023	3.5	3.3	3.3	3.2	3.7	3.6	4
Luxembourg	2023	3.6	3.6	3.6	3.6	3.9	3.5	3.5
Montenegro	2023	2.8	2.6	2.5	2.8	2.8	3.2	3.2
Netherlands	2023	4.1	3.9	4.2	3.7	4.2	4.2	4
Poland	2023	3.6	3.4	3.5	3.3	3.6	3.8	3.9
Portugal	2023	3.4	3.2	3.6	3.1	3.6	3.2	3.6
Serbia	2023	2.8	2.2	2.4	2.9	2.7	2.9	3.4
Slovenia	2023	3.3	3.4	3.6	3.4	3.3	3	3.3
Switzerland	2023	4.1	4.1	4.4	3.6	4.3	4.2	4.2
United Kingdom	2023	3.7	3.5	3.7	3.5	3.7	4	3.7
Region: Europe & Central Asia	2023	3	2.9	2.9	2.8	3.7	3	3.2

In Table 2, Germany's LPI scores are compared with 18 European countries. In addition, it was compared with the averages of European and Central Asian countries. This comparison is given in Table 2 according to 6 LPI dimensions. This comparison was made based on 2023 data. The first column shows the countries. Table 2. The third column of is included in the LPS score. There is customers score in the fourth column, infrastructure score in the fifth column, international shipments score in the sixth column, logistics competence score in the seventh column, tracking & tracing score in the eighth column and timeliness score in the eighth column.

Accordingly, when we examine Table 2, Germany's scores are quite high in almost all dimensions compared to other countries and the European average. This supports the idea that Germany is the right option when we examine it from a different perspective. It is to make Germany as attractive as Türkiye, which ranks first in exports, for opening warehouses and intermodal transportation.

Intermodal transportation from Türkiye to Germany requires the integration of various transportation modes. In this process, optimization of warehouse layout has great potential to reduce costs and increase environmental sustainability.

Additionally, studies addressing the integration of warehouse location selection and transportation modes together are limited in the literature. This thesis aims to fill this gap and provide innovative solutions in logistics management. The developed mathematical model and analyses make significant contributions to academic literature and offer practical solutions to businesses. Therefore, this thesis topic has been chosen in line with both academic and practical requirements. This study is about a hypothetical company that operates intermodal transportation from Türkiye to Germany. This company decides to open one or multiple warehouses in Germany to reduce costs.

This study discusses the mathematical model and its applications developed to optimize the warehouse layout decisions of a company engaged in intermodal transportation from Türkiye to Germany. The model aimed to minimize total transportation and warehouse costs and was tested with randomly generated data sets. By integrating different transportation modes, costs have been reduced and environmental sustainability has been indirectly achieved. These findings provide important insights to help make strategic decisions in logistics and supply chain management. The study results provide practical solutions for businesses to increase operational efficiency and reduce indirect environmental impacts.

The aim of this thesis is to determine the most appropriate warehouse sub-setting among the daily warehouse options that serve. The aim of this thesis is to determine the most appropriate subset of warehouses among the candidate warehouses set. When making this choice, the aim is to minimize the total transportation and warehouse agreement costs. Transportation is costly and requires many environmental, financial and time resources. Thus, transportation is both a costly task and requires many environmental, financial and time resources.

The thesis deals with a company that carries out intermodal transportation starting from Türkiye, a developing country, to Germany, a developed country. At every stage of this thesis, the data closest to reality is used. We are solving real life problems. While calculating the transportation cost, we optimized it by taking into account even the change in gasoline costs resulting from the size differences of the vehicles. In addition, we calculated the gasoline cost per kilometer of each vehicle in euro currency, according to the latitude and longitude values of the destinations. In addition, we determined the capacities and prices of each candidate warehouse to be optimized according to the information obtained from the actual warehouse advertisements. We set lower and upper limits for modes, warehouses and FTL. The reason for this was to obtain a more realistic result.

In addition to building a mathematical model, we create realistic data sets with randomly generated components. We model the process from the starting point, the main base warehouse of the company in Türkiye, to the final delivery points as close to reality as possible. We determined different capacities and prices for candidate warehouses. For this, we used real warehouse advertisements. We considered different modes of transport. We propose a mathematical model and perform tests using data from randomly generated instances. We change the values of several parameters and observe the change in the objective value and decision variables. We report the results by establishing a cause-and-effect relationship.

The outline of this study is as follows. After a literature review in Section 2, we define the problem definition and the methodological framework in Section 3. We present the results of computational experiments in Section 4. Section 5 includes discussions on the shortcomings. The last section concludes this study.

CHAPTER 2: LITERATURE REVIEW

In this section, we present the related literature on the optimal warehouse location in an intermodal transportation network. Facility location and warehouses selection in Section 2.1, we define multimodal transportation Section 2.2, intermodal transportation in Section 2.3 and application transportation optimization in Section 2.4.

2.1 Facility Location and Warehouse Selection

Facility location selection is one of the important decisions that affect all supply chain decisions and performance. We initially analyzed the facility location problem as our first subject of study.

Owen and Daskin (1998) mention about geography of a business's country or countries on which location (land) it will be established. The process of determining the establishment is called choosing the location of the facility. The location of the facility is determined by the fundamental operations of supply, production, storage, and distribution. It can be defined as the optimal location for facilities where enterprises can achieve their objectives most efficiently. An optimal facility location significantly decreases operational expenses and minimizes quantifiable factors.

The Importance of Facility Location Selection

- If the raw material supply problem decreases.
- Marketing problems are reduced.
- Cost control becomes easier.
- Labor supply problems decrease.
- Maximum benefit is made from government incentives.
- Uncontrolled costs are reduced.
- Unit production costs are minimized
- Competitive advantage obtained.

While determining the business strategy, the goods and services that the company will offer are determined. The market in which it will compete is certain. Facility location selection is a long-term and strategic decision. It is a long-term investment decision. It is difficult and costly to replace. However, it is still a dynamic decision. When deciding on the location of the facility, capacity and demand should be taken into consideration. Especially in service businesses, location of facility determines demand. Capacity is determined according to demand. Therefore, decisions must be made together. An inadequately selected facility location; high transportation expenses, sufficient labor and raw materials unaffordability, competitiveness and financial causes losses (Kurgan, 2021).

Wang et al. (2018) The competitive location problem involves the establishment of new facilities that can effectively compete with existing facilities for certain customers. The competitive location model assumes that consumers want to choose the nearest facilities, while each facility aims to cover the largest feasible region. Aboolian et al. (2007) argue that the nearest establishment may not necessarily offer the highest level of attractiveness. Both maximizing attractiveness and minimizing distance are crucial.

Aboolian et al. (2007) choose facilities that will compete with each other for client demand, as well as with current facilities. They are seeking solutions to three fundamental inquiries for their optimization.

1. What is the optimal number of facilities?
2. Where these facilities should be situated?
3. What kind of facilities (in terms of dimensions, range of products, and other design elements) should be situated?

These questions are evidently interrelated. For instance, the size of the facilities is directly related to this, as fewer larger facilities can be utilized as substitutes for smaller facilities. Throughout the experiments conducted in our study, our model consistently demonstrated a tendency for favoring the opening of larger warehouses.

The logistics sector is experiencing a steady increase in its contribution to the economy and is characterized by high circulation levels. This problem garners the attention of both prominent trade participants and authorities. There is a high level of demand for new logistics and distribution facilities across Europe, such as warehouses, distribution centers, and transfer warehouses, with a particular emphasis on Germany. Given Germany's strategic location, this scenario had much greater significance for them. The German government and municipalities offer favorable assistance about the utilization of new facility sites. This study focuses on selecting a new warehouse site and was carried out using the city of Hamburg as the basis. They stayed clear of congested locations. In our study, the main focus is on the aspects of commerce and the geographical positions of the pertinent logistics firms. We analyzed the geographical areas with a high concentration of German logistics business. The research was conducted in the Hamburg area. The average journey production rates for transportation are explained empirically through analysis. Many analyses of planning parameters were conducted for comparison. Various logistics land use development scenarios were generated by utilizing the survey findings. The findings indicated that the smart placement of logistical hubs can mitigate traffic congestion. This study has arrived at a social inference by adopting an alternative viewpoint on the significance of choosing a warehouse location (Wagner, 2010).

Facility location covering problem is a widely studied problem. Wang, Wu and Wang (2021) present a comprehensive analysis of the problems associated with locating emergency facilities, such as schools, hospitals, fire stations, ambulances, and emergency rooms, which are all instances of public facility installations.

Wang, Wu and Wang (2021) solve the location covering problems, it is aimed to minimize the transportation time or distance to the demands of a particular region. We have basically constructed a similar mathematical model. We both considered the demands of the customers, the distance to the demands and whether the warehouses should be opened accordingly. However, in our study, unlike this, we ran it using a mathematical model in the GAMS program. Then we supported it with experiments.

Basti (2012) P-median problem is a type of location covering problems. In p-median problem, the locations of the candidate facilities, the customer points, the demand of each customer, the distances between all facility-customer point pairs and a number of facilities to be opened are known. The objective is to select the best subset of candidate facilities to minimize the total demand-weighted distance of customers to the closest facility.

Transportation is critical for facilitating the movement of people and goods between different regions, nations, and the entire globe. We can imagine transportation networks as complex networks, where nodes represent various sites like cities, airports, or ports, and lines represent the connections or routes that connect them. Recognizing the traffic dynamics within networks using complex networks is crucial for maintaining the effectiveness of transportation systems.

2.2. Multimodal Transportation network

Zhang et al. (2024) focuses on the development and progression of novel transportation systems have resulted in the merger of many modes of transportation. A multimodal transportation network consists of two or more transportation modes.

Multimodal transportation refers to the practice of transporting cargo or freight using multiple means of transportation. The shipper needs to manage a single contract. Multiple organizations may handle the delivery process, but the shipper merely engages in one negotiation to establish an agreement with all of them. However, we should note that it is more common to transport goods through just one corporation and a single commercial agreement.

In multimodal transport, a single enterprise bears most of the obligation instead of an even distribution. Moreover, multimodal transportation offers the shipper a significant benefit in terms of simplicity, as it requires only one contract.

However, the carrier faces a greater level of complexity. While certain organizations may have the capability to handle multimodal transport comprehensively, others may need to seek assistance from other businesses if they lack a particular form of transportation. Ultimately, freight forwarders or agents may oversee the operation of multimodal transportation. These organizations do not physically transport goods but instead have extensive networks of carriers. They can assist in negotiating contracts and even handle the entire shipping process independently. Many writers have tackled the issue of multimodal transport, putting forth various algorithms and abstractions. There are many multimodal transport routing alternatives. This approach is utilized for many different optimization problems (Banomyong and Beresford, 2001); multimodal transportation networks (Qu and Chen, 2008); shame for application in transportation model (Zhang et al., 2010); time-dependent multimodal transportation problems (Ayed et al., 2011); route selection in multimodal transportation (Kengpol et al., 2012a, b; Kengpol 2014).

Kengpol et al. (2014) emphasize the significance of route selection in multimodal transportation networks and developed a model that simultaneously considers transportation costs, lead time, risks, and CO2 emissions. Kengpol et al. (2014) and Emre (2022) both consider minimizing the total cost, time, carbon footprint, and risks.

Zekhruf, Frazila and Burhani (2022) consider the multimodal transportation network used to deliver goods to disaster areas during disasters, such as earthquakes and tsunamis. They built a fundamental structure similar to our study. Despite having distinct names, a product possesses a designated point of departure, is gathered at intermediate central locations, and is ultimately given to those who require it. This network possesses a parallel structure to ours.

Song, Yu and Li (2023) approach multimodal transportation from a different point and discuss a company that transports hazardous materials. An analysis was conducted on the rising frequency of traffic accidents and the duration of time spent on the road. Analysis took place on individual road, maritime, and railway information to investigate accident rates. Afterwards, the practice of multimodal transportation has been examined in the transportation of hazardous materials. The main emphasis is on the strategic planning, imaginative design, and efficient route optimization. The formulation was developed using non-linear, mixed integer programming. An enhanced ant colony algorithm was developed specifically for the model. Empirical case study was undertaken. The routing challenge of minimizing both risks and costs is formulated using a mathematical model. Upon analyzing the findings of this article, our objective is to mitigate the potential hazards by employing alternative routing strategies.

2.3 Intermodal Transportation Network

Intermodal freight transportation refers to transferring goods from one place to another using many modes of transportation, including air, inland water, ocean, train, and road Chang (2007). The objective is to offer a smooth and uninterrupted service from one's starting point to their destination. The complexity of international multimodal routing is influenced by three significant problem elements.

1. It is crucial to incorporate many objectives, such as reducing journey time and travel costs, as shippers may have varying concerns.

2. The routing design should be incorporated into Transportation mode schedules and delivery timings. Otherwise, specific routes that are situated may become impracticable in a real-world scenario. The current schedules and requested delivery times might be considered time window limits.

3. When calculating transportation costs, it is important to consider the impact of economies of scale (EOS), as the costs of most forms of transportation are influenced by the overall weight being moved.

Caris, Macharis and Janssens (2008) focuses on the problem of an international intermodal carrier choosing the best routes for shipments. Demand delivery times and economies of scale are crucial for this problem. Our problem is that the slaughterhouse is only a matter of intermodal transportation. In this article, there is a solution to an operational problem using meta-heuristic methods to increase this operational intermodal performance.

Wei et al. (2024) consider the intermodal freight transportation networks (IFTNs) are essential for global freight transportation as they combine several transportation modes to provide cost-effective, efficient, and secure freight transfer.

Ozpeynirci, Ucer and Tabaklar (2014) define multimodal Transportation; A form of transportation in which more than one type of transportation (land, air, sea, railway, pipeline) is used sequentially and the load is handled directly in transfers between types.

Intermodal Transportation; It is done by using two or more modes of transportation with the same transportation vehicle or container. It is a transportation model in which the loads in the vehicle or container are not subjected to any handling during mode changes, but the vehicle or container is handled. Figure 2. also shows this definition in the intermodal transportation scheme. We see that the transport mode of containers changing from the origin point to the destination point.

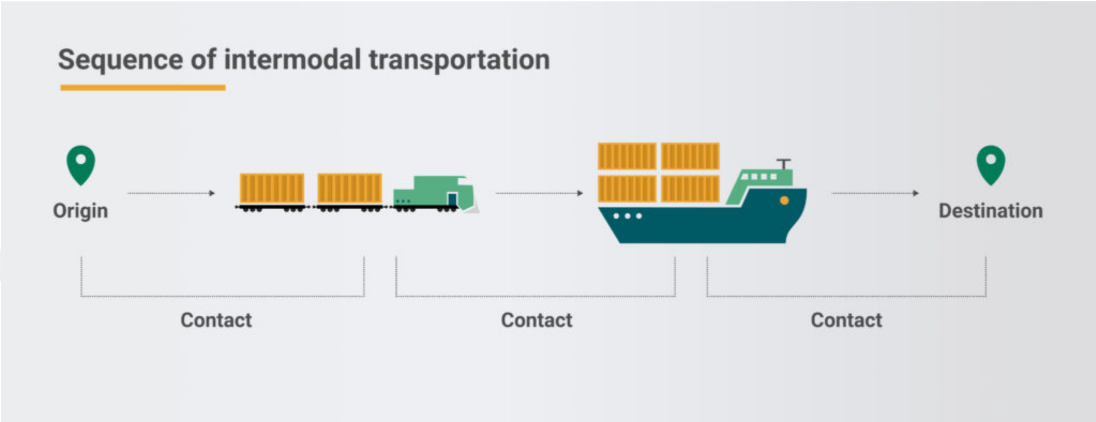


Figure 2. Intermodal Transportation Schema May 2019, (xChange solution GmbH, 2019)

Ertem, Akdogan and Kahya (2022) approach intermodal transportation in humanitarian logistics. Their purpose is to ensure that beneficiaries benefit from intermodal connections in the event of a disaster. Using multiple modes of transportation (e.g. road, rail and sea) expands the range of options for humanitarian organizations. The main purpose of this research is to develop a mathematical model for the selection of different intermodal transportation mode combinations in humanitarian logistics. This research very well emphasizes the importance of intermodal transportation on the issue of humanitarian aid. Issues requiring humanitarian assistance are urgent. Time is of the essence and there should be no margin for error. The fact that intermodal transportation was chosen for such a situation is an indication that this transportation method has lower risks and is optimal.

Gandhi et al. (2024) describe intermodal transportation as the practice of transporting goods using multiple modes of transportation, such as trucks, trains, and ships, to efficiently navigate the various firms involved in the process. Every firm is accountable for one or multiple means of transportation; however, the client enters into contracts with each company separately. Therefore, because of the structure of intermodal transportation, the liability for the cargo is equitably split among all organizations involved. Each party is solely accountable for the cargo's safety and security exclusively during the shipping, loading, and unloading processes, with no additional responsibilities beyond that. Intermodal transportation is naturally more complicated and susceptible to problems in contrast to multimodal transportation. Handling many contracts and coordinating with multiple businesses for deliveries introduces complexity to the shipping process.

The utilization of an intermodal logistics network for delivery has shown to yield reduced expenses and less congestion compared to the predominant mode of transportation. Growing highway congestion has been influenced by environmental factors. Therefore, they take a strategic approach to this problem. They formulated this model as a non-linear model. This work was focused on the mathematical model of the freight flow assignment problem under auction equilibrium. (Krylatov and Raevskaya, 2023).

2.4. Application in Transportation Optimization

Koç et al. (2016) consider with effects of warehouse location, fleet composition and routing decision on emissions in city logistics and provides real-life examples. They have an approach to the subject similar to our study with some disparities. This article establishes distinct zones based on the spatial separation between two places. Fuel quantities and CO_2 emissions were computed consistently for every situation. The target function aims to minimize the overall cost, encompassing gasoline, CO_2 emissions, and fixed expenses related to tanks and vehicles.

Xinghan Chen et al. (2022) explore the concept of an integrated Highway-Railway optimization. The utilization of an intermodal transportation network is employed. Objective developing optimized rail timetables to more effectively accommodate freight demand. The aims of this essay are to optimize the average rail capacity: Reducing the utilization and quantity of transfer stations in transportation and expenses and additional charges due to shipping delays. In contrast to our study, we did not incorporate a limitation, such as minimizing warehouse usage, into our mathematical model for warehouse selection. We consider a scenario that forces the model to open at least one warehouse. Our study differs in this particular component.

Gazran et al.(2023) discuss the contemporary technologies and the subsequent implementation of an optimization study on it. This article seeks to optimize efficiency in the supply chain. The study employed a Mixed Integer Linear Programming paradigm. The decisions made encompass the choice of potential terminal sites, the quantity of trucks, the source and destination of items, and their movement over direct and backhaul routes. The objective is to minimize the total transportation expenses, encompassing expenditures related to the terminal site, fixed expenses for both regular and platoon trucks, as well as fuel and driver costs and analyzed many scenarios. This study shares many similarities with the present investigation in this thesis. Initially, we presented our findings by conducting scenario analyses on the outcomes collected from random data in our study. We conducted a study to reduce warehouse expenses and transportation expenses.

Camur et al. (2024) propose an optimization framework for efficient and sustainable logistics operations using transportation mode optimization and shipment consolidation. They conduct a case study for the global distribution of General Electric (GE) to its suppliers. Products transport to manufacturing and assembly locations in the United States using different modes of transportation, such as water, air, and land. Optimization is required for the modes. There is the option of intermodal transportation. In light of the complex transportation infrastructure and substantial workload, they sought to enhance the efficiency of their shipments by strategically locating intermediate storage facilities. Computational experiments have been conducted. There are many similarities between the present study and it. Having a tangible, real-life example is of utmost significance. It provides a solution to an industrial problem, benefiting both the sector and the academy. However, the process of optimizing the intricate intermodal network structure is intricately linked to my thesis. In our investigation, we employed an intermodal network. Our objective was to choose the most appropriate warehouse among the available options. We have documented the outcomes.

Ferjani et al. (2024) examine the integration of manufacturing, transportation, operation, and maintenance, which has the potential to result in inefficient supply strategies. A mixed integer linear programming model was developed with the objective of minimizing the overall production costs, and transportation expenses, and maximizing the operational utility of the equipment. In addition, a two-stage memetic method has been developed to address the problem. This study proceeded with the investigation focusing on a manufacturing company. Thus, in contrast to our study, it specifically emphasizes operational characteristics. Furthermore, it also highlights the significance of equipment efficiency and production efficiency.

Dereci and Karabekmez (2022) aim to minimize the total transportation costs while choosing the suitable routes and the warehouse among the candidate warehouses. The presence of a large number of people and the generation of a significant amount of solid waste provide challenges in identifying the optimal path for garbage collection vehicles in urban areas. Furthermore, inadequately designed routes result in the squandering of fuel, time, and other resources throughout the municipality's waste-collecting procedure. The Vehicle Routing Problem (VRP) is a mathematical problem that involves finding the optimal routes for a certain number of vehicles, starting from a warehouse, visiting all clients, and returning to the warehouse. It employs meta-heuristic methodologies to efficiently and effectively solve real-world problems. The purpose is to offer a method for optimizing routes. The objective is to identify paths that offer the smallest distance throughout the entire procedure. The problem is solved using heuristic and meta-heuristic methods. In our study, a mathematical programming model was used. The company engages in intermodal transportation. There are candidate warehouses. Optimization was made for candidate warehouses. It is aimed to minimize warehouse fixed costs and transportation costs. The data closest to real life was used. Transportation costs for products leaving the warehouse have been reduced. Since the possibility of transportation with a smaller vehicle is taken into account.

CHAPTER 3: PROBLEM DEFINITION AND METHODOLOGY

We consider a hypothetical company that provides intermodal transportation services between Türkiye and Germany. To minimize its overall transportation costs, the company has decided to establish warehouses in Germany. Selecting the most suitable locations among the candidate warehouses is crucial for optimizing total costs, considering not only the direct transportation expenses but also the long-term operational efficiency that these warehouses could bring to the supply chain.The movement of goods from Türkiye to Germany can be facilitated through three main modes of transportation: road, sea, or rail. Each mode has distinct characteristics that influence its suitability, depending on factors like distance, freight volume, and environmental impact.

Road transportation offers flexibility and speed, especially for short distances and the final stages of delivery. It allows for a direct, point-to-point distribution system that can quickly meet customer demands, making it ideal for last-mile logistics. The adaptability of road transport is essential for businesses that need to respond to changing market conditions or unexpected demand surges. According to logistics theory, the efficiency of road transport in terms of reduced lead times is a significant advantage in maintaining high customer satisfaction, which is critical for companies operating in competitive markets. Sea transportation, on the other hand, stands out for its ability to move large quantities of goods over long distances at a lower cost per unit. Maritime transport is particularly cost-effective for bulk cargoes, such as raw materials or manufactured goods, and is one of the most energy-efficient modes of transport. The Türkiye Ministry of Transport and Infrastructure (2023) highlights that maritime transport offers both cost savings and environmental sustainability by reducing fuel consumption compared to road and air freight. This mode is often preferred when delivery times are more flexible, and large, non-time-sensitive shipments are involved. Pita and Anton (2023) further emphasize that the scale of sea transport allows companies to leverage economies of scale, which is crucial for industries with high-volume shipments.

Rail transportation provides a balance between cost efficiency and environmental sustainability. Rail systems are highly efficient for moving large amounts of cargo over long distances and are less affected by traffic or weather disruptions than road transport, making them a reliable option for long-haul shipments. Furthermore, rail emits significantly fewer carbon emissions compared to road transport, enhancing its appeal from a sustainability perspective. Theories of green logistics emphasize rail transport's role in reducing the environmental impact of supply chains, aligning with the growing corporate responsibility for sustainable practices. By choosing rail, companies not only cut costs but also support broader environmental goals, such as reducing their carbon footprint and complying with increasingly stringent environmental regulations.

Additionally, the choice of transportation mode depends on the nature of the goods being shipped and the company's strategic goals. For instance, perishable goods may require faster delivery options like road transport, while non-perishable bulk goods are better suited for sea or rail transport. The selection process also involves a trade-off between transportation costs and the level of service provided. This is where intermodal transportation strategies come into play, offering a combination of different transport modes to optimize both cost and time. The integration of different modes, such as using rail or sea for the main leg of the journey and road for the last-mile delivery, can significantly improve supply chain performance.

In conclusion, the company must carefully evaluate the advantages of each transportation mode while considering the costs, environmental impact, and service level requirements. Road transport offers flexibility and speed, sea transport is cost-effective for large shipments, and rail provides a reliable and sustainable solution for long-distance transport. By strategically utilizing these modes, the company can optimize its supply chain, reduce costs, and improve service delivery to customers across Germany.

After arriving at the German border gates, one of the options is direct delivery to the customer. Another option for the load to land at the warehouse and then be delivered to the customer. Figure 3. presents the transportation network and the possible material flows.

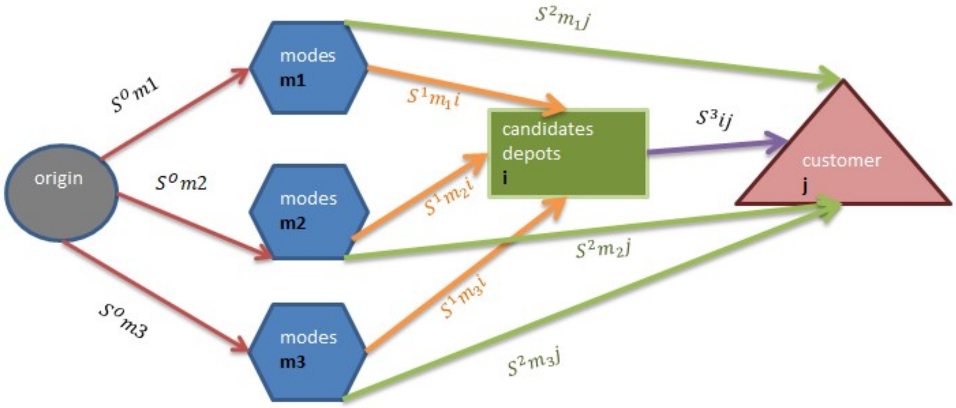


Figure 3. The Transportation Network and The Material Flows

We develop a mathematical programming model as our methodology for this problem. We prepare a realistic data set with random components and solve the model using this data set. We also conduct a scenario analysis by changing different problem parameters and checking the robustness of the model to these changes.

We present the developed mathematical model and discuss the sets, parameters, decision variables, objective function and constraints. Our set has three elements. These are modes, candidate warehouses and customers.

The basic mathematical model of this study is as follows:

Sets:

Modes m / 1, 2, ,…/

Each mode represents a different way for transporting goods from Türkiye to Germany. Some possible modes include Road, RoRo, and RoRo+Train.

Candidates warehouses i /1,2,…/

Each candidate warehouse is an option for providing final delivery services to the customers. We consider realistic warehouse locations in the experiments.

Customer j / 1,2,…/

Each customer has a certain demand to be satisfied and the locations of the customers are known.

Parameters:

C_m^0 : unit transportation cost of mode *m* per vehicle

C_{mi}^1 : unit transportation cost from mode *m* to warehouse *i*

C_{mj}^2 : unit transportation cost from modes *m* to customer *j*

C_{ij}^3 : unit transportation cost from *i* warehouses to customer *j*

f_i: fixed cost of open warehouse *i*

d_j: demand of customer *j*

Decision Variables:

S_m^0: amount of origin to mode *m*

S_{mi}^1: amount of shipment to warehouse *i* via mode *m*

S_{mj}^2: amount of direct shipment to customer *j* via mode *m*

S_{ij}^3: amount of shipment from warehouse *i* to customer *j*

y_i= 1 if warehouse *i* is opened and

0 otherwise

Objective Function:

$$Min\ Z = \sum_m C_m^0\, S_m^0$$

Cost from origin to mode m

$$+\sum_m \sum_i C_{mi}^1\, S_{mi}^1$$

Cost from mode m to warehouse i

$$+\sum_m \sum_j C_{mj}^2\, S_{mj}^2$$

Cost from mode m customer j

$$+\sum_i \sum_j C_{ij}^3\, S_{ij}^3$$

Cost from warehouse I to customer j

$$+\sum_{i} f_i\, y_i$$

fixed cost of opening a warehouse i

Constraints:

$$\sum_{i} S_{ij}^{3} + \sum_{m} S_{j}^{2} \geq d(j)$$

Amount of inflow products must be greater than or equal to customer demand

$$S^{O} m = \sum_{i} S_{im}^{1} + \sum_{m} S_{mj}^{2}$$

The amount of products in mode m must be equal to the sum of the amount of products outflow from mode m

$$\sum_{m} S_{mi}^{1} = \sum_{J} S_{ij}^{3}$$

The total amount of products inflow the warehouse i, It should be equal to the total amount of products outflow from warehouse i to customer j

$$\sum_{m} S_{mi}^{1} \leq y_i \mu$$

If warehouse i is open, products must go to warehouse i from mode m. So, it should serve

After developing this mathematical model, we have created a realistic instance using random data. The aim of the model is to minimize the total transportation and warehouse agreement costs.

By systematically changing various parameter values in the model, we observed the changes in the optimal results. Each time, we change only one parameter value and analyze the optimal solution using to the following indicators:

- Objective function
- Number of open warehouses
- Warehouses ratio
- The ratio of transportation costs to total costs
- The ratio of fixed costs to total cost

We change the values of the following parameters in our experiments:

- Ratios of warehouse capacities
- Fixed cost ratio for opening warehouses
- Full truckload (FTL) ratio
- Customer demand ratios
- Transportation cost ratio

CHAPTER 4: COMPUTATIONAL EXPERIMENTS

In this chapter, we present the details of the computational experiments. We first discuss the data generation methodology. Next, we present the optimal solution of the model. Finally, we conduct a scenario analysis and analyze the robustness of the model.

4.1 Data Generation

We conduct a search on several professional web sites to determine the potential warehouse locations and the related fixed and operating costs. We also search for alternative transportation options from Türkiye to Germany. Based on our search results, we generate controlled random data as the base scenario. Figure 4. shows a sample map for a company that carries out intermodal transportation from Türkiye to Germany. We use GAMS Cplex solver for optimizing all mathematical models.

Figure 4. Geographic Representation of The Problem Region

There are three different sets of sections in the model. These are candidate warehouses, customers and transportation modes.

We identified 12 different candidate warehouses in Germany. The capacities and prices of these warehouses differ from each other. We used real data for candidate warehouses, capacity and prices. We used local warehouse rental websites in

Germany. We looked at warehouse rental advertisements for one year and longer than one year. We chose the ones with relatively large capacities. We took these values as our reference.

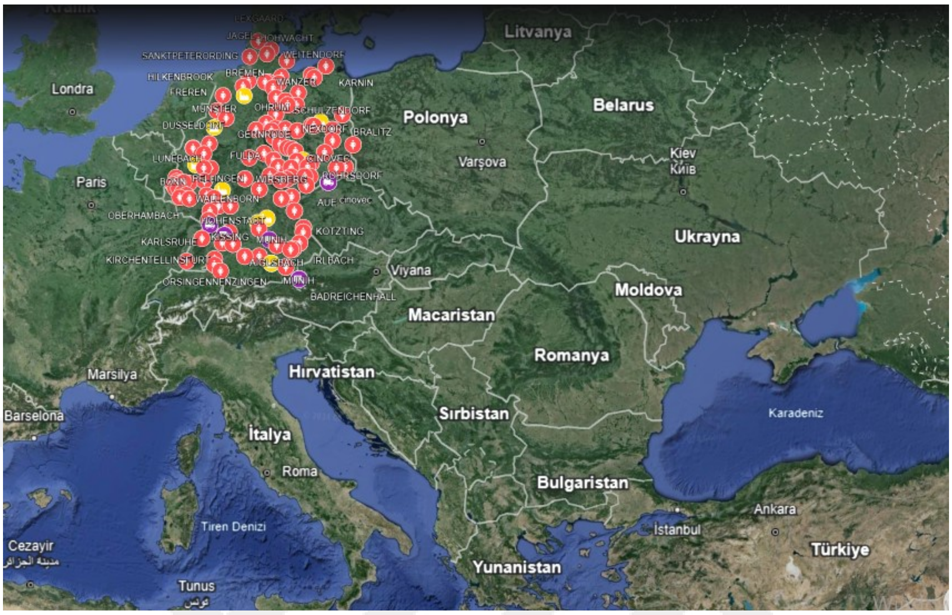


Figure 5. Geographic Distribution of Locations Used in The Model

We have determined five different entry modes and points for receiving. After using any of the three transport modes from Türkiye to Germany, we determined where the freight could be in Germany. That's why we chose the places with the most transportation on the German border. We identified 107 customers waiting to receive service at different points in Germany and selected the demand amounts of each customer differently. Even though we randomly determine the demand points, we tend to choose places near logistics centers and logistics villages. In addition, since we thought that the places where large industrial companies are located could be centers of attraction, we made sure that these regions were included in the data set we selected. Figure 5 shows the geographic distribution of the locations used on the model and Figure 6 provides a focused view in Germany. In both Figures, the places marked in yellow represent warehouses, the places marked in red represent customers, and those marked in purple represent modes. We made our research more realistic by setting lower and upper limits for the capacities of the warehouses, the load carrying capacities of the modes and Full Truck Load. However, we have added some constraints. In this way, we ensured that all products coming from Türkiye were transported to customers, and we ensured that all products coming to the warehouse reached their demand points. We attach importance to meeting all customer demands. However, whichever of the candidate warehouses was opened, we ensured that the opened warehouse was used effectively. In this way, we prevented additional costs that may arise. We use four constraints in this manner to optimize the problem. Thanks to these restrictions, we ensure that all incoming products meet customer demand. We make sure that the products coming to the mods meet the demands. We ensure that all products arriving at the warehouse reach the customers. If any of the candidate warehouses is open, we ensure that the open warehouse is used. In this way, we try to optimize the cost. We provide service to all customers' demands.

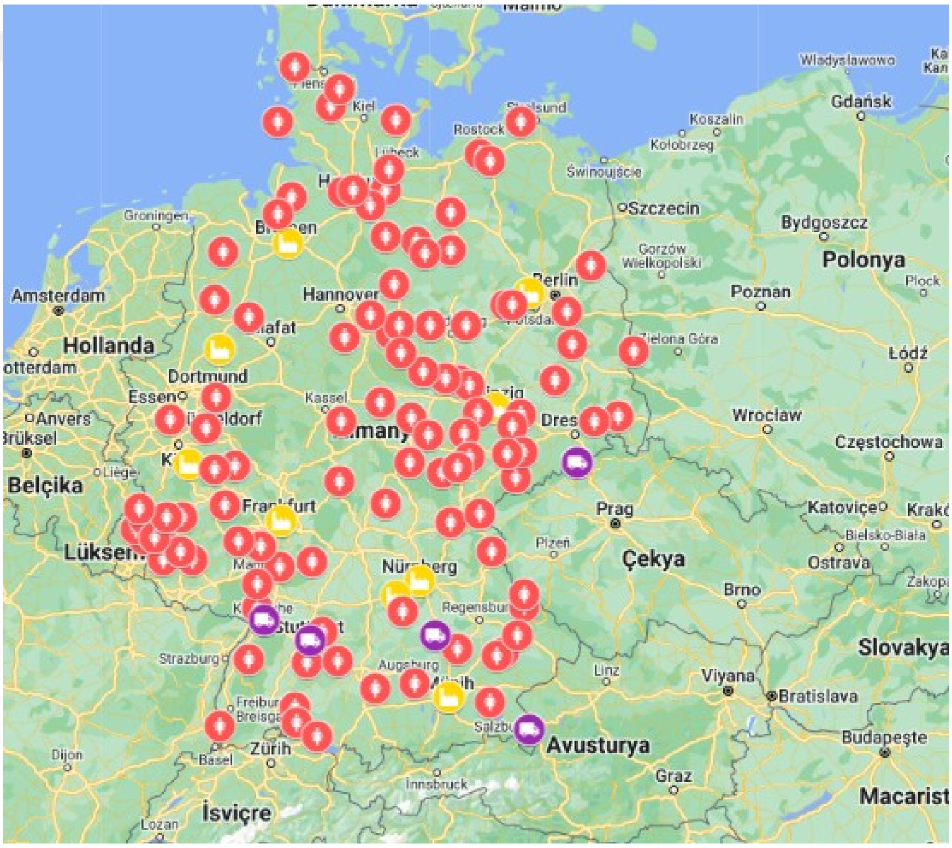


Figure 6. Locations of The Warehouses, Customers and Modes

In this problem, the cargo leaving the origin point chooses one of the different transportation modes and then arrives at one of these German border gates. We defined the part up to this stage as *Stage 0*. In the next stage, it may be possible to enter the customer directly from the border gates as a full truckload. We defined this stage as *Stage 1*. It may be possible to go from the border gate to the warehouse. We defined this as *Stage 2*. It may be the case that it goes from the warehouse to the customer as a less truckload. We defined this as *Stage 3*.

For each of the Stages 0, 1, 2 and 3 roads, we take into account the fuel cost of the truck per kilometer in direct proportion to the distance and the fuel costs of small vehicles in case of transfer from the warehouse. We calculate the cost for each route. We include this in the parameters section of the GAMS model.

Although per kilogram shipment cost is cheaper for full truckload shipments compared to less than truckload shipments, a customer may not receive only full truck shipments throughout the year. Some shipments have to be LTL for several reasons, such as demand fluctuations (e.g., high or low seasons), equipment shortages or last-minute cancellations. To include such operational imperfections in our model, we determine lower and upper limits for the full truckload to be sent to each demand point.

We have set lower and upper limits for each transportation mode. In addition, we defined positive variables. We set amount for stage 0, stage 1, stage 2, and stage 3.

In the objective function, we aim to minimize warehouse and transportation costs. However, we added some constraints to make it more realistic.

I. The quantity of incoming products must be greater than or equal to customer demand.
II. The amount of product in mode m must be equal to the sum of the amount of product coming out of mode m.
III. The total amount of product entering warehouse i must be equal to that of the product leaving warehouse i to customer j.
IV. If warehouse i is opened, products must go from mode m to warehouse i, so it must provide service.

Due to these constraints, we ensured that service was provided to all customers.

We prevented the opening of additional warehouses. We have pushed to reduce the fixed costs of opening warehouses.

4.2 Scenario Analysis

We observed the change in the optimal result by systematically changing various parameter values in the model. We change one parameter at a time record the optimal solution, objective value, number of opened warehouses, ratio of transportation costs to total cost. It is examined with its values. Parameters to be changed at each scenario are as follow

I. Ratios of warehouse capacities
II. Fixed cost rate of opening warehouses
III. Full truckload (FTL) rate
IV. Customer's demand rates
V. Transport cost rate

We systematically adjusted the ratio of each parameter from 25% to 200%, while maintaining all other variables constant.

4.2.1. Ratios of Warehouse Capacities

Table 3 presents the ratios of warehouse capacities, with the first column showing the variations in the warehouse capacity ratio, which we adjusted between 25% and 200%. In this analysis, only the warehouse capacity ratio was modified, while the fixed cost ratio (second column), Full Truckload (FTL) ratio (third column), demand ratio (fourth column), and transportation ratio (fifth column) were held constant. The sixth column displays the minimum z values, representing the objective function values. The seventh column reflects the percentage change in the objective function corresponding to each change in the warehouse capacity ratio.

Additionally, we calculated the transportation cost, fixed cost, and warehouse ratio. Transportation cost is shown in the ninth column, while fixed cost is presented in the tenth column. The comparison of the fixed cost to the objective function is outlined in the eleventh column. The twelfth column provides the storage rate, and the thirteenth column lists the number of warehouses opened among the candidate warehouses based on changes in the warehouse capacity ratio.

To better interpret the results, we compared the transportation cost to the minimum z value and similarly compared the fixed cost to the objective function value, expressing both as percentages. This percentage comparison facilitates easier analysis, showing that the changes in warehouse capacity ratio affected the total cost by approximately +/- 4%. However, transportation and fixed costs remained largely unaffected by these changes, and the number of warehouses opened did not vary as the warehouse capacity increased or decreased.

Table 3. Ratio of warehouse capacities

Depot Cap Ratio	Fixed Cost Ratio	FTL Ratio	Demand Ratio	Transportation Cost Ratio	Min z	z%	TC/z %	Transportation Cost (TC)	Fixed Cost (FC)	FC/z %	Depot Ratio	Number of Depots
25	100	100	100	100	21,170,987	104	99	20,932,187	238,800	1	0.07	2
50	100	100	100	100	20,838,574	103	99	20,599,774	238,800	1	0.14	2
75	100	100	100	100	20,532,484	101	99	20,293,684	238,800	1	0.21	2
100	100	100	100	100	20,262,452	100	99	20,023,652	238,800	1	0.28	2
125	100	100	100	100	20,025,904	99	99	19,787,104	238,800	1	0.35	2
150	100	100	100	100	19,826,179	98	99	19,587,379	238,800	1	0.42	2
175	100	100	100	100	19,657,104	97	99	19,418,304	238,800	1	0.49	2
200	100	100	100	100	19,524,805	96	99	19,286,005	238,800	1	0.56	2

4.2.2. Fixed Cost Rate of Opening Warehouses

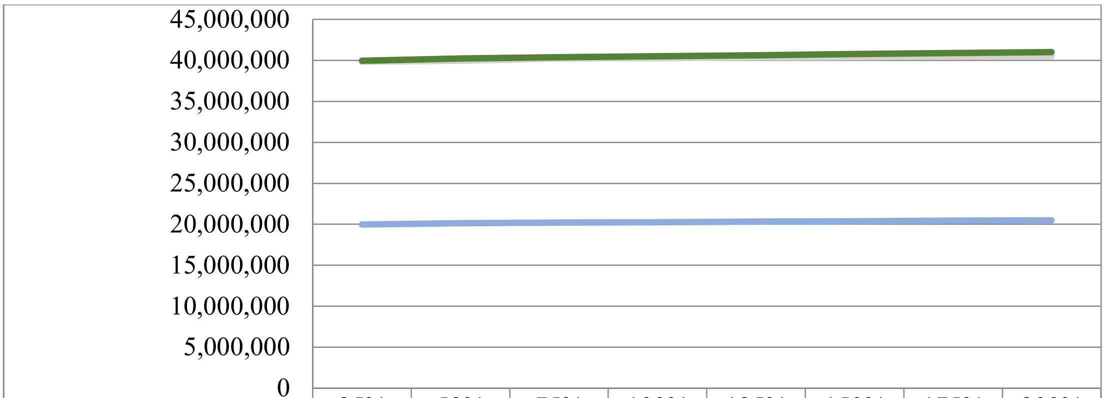
Table 4 presents the fixed cost rates for opening warehouses. In this analysis, we examined the variation in fixed cost rates, ranging from 25% to 200%. The first column contains the warehouse capacity ratios, the second column shows the fixed cost ratios, the third column lists the Full Truckload (FTL) ratios, the fourth column contains the demand ratios, and the fifth column shows the transportation ratios. The warehouse capacity ratio, FTL ratio, demand ratio, and transportation ratio were held constant throughout this analysis.

The minimum z values, which represent the objective function values, are displayed in the sixth column. The seventh column shows the percentage change in the objective function based on changes in the fixed cost ratio. The ratio of transportation costs to the objective function is presented in the eighth column. Additionally, we calculated transportation costs, fixed costs, and warehouse ratios. These results are provided in the ninth column (transportation cost), tenth column (fixed cost), and eleventh column (percentage ratio of fixed cost to the objective function), respectively. The twelfth column lists the warehouse ratios.

To better interpret the results and the changes in values, we compared the transportation cost to the minimum objective function value (min z). We also calculated the percentage of the fixed cost relative to the objective function value (min z) for easier analysis. The variations in fixed cost ratio led to only minor changes in total cost and transportation costs. However, as the fixed cost for opening warehouses decreased, it resulted in the decision to open additional warehouses. Consequently, while transportation costs decreased in locations where warehouses were opened, the fixed costs increased correspondingly.

Table 4. Fixed cost rate of opening warehouses

Depot Cap Ratio	Fixed Cost Ratio	FTL Ratio	Demand Ratio	Transportation Cost Ratio	Min z	z%	TC/z %	Transportation Cost (TC)	Fixed Cost (FC)	FC/z %	Depot Ratio	Number of Depots
100	25	100	100	100	19,989,801	99	99	19,866,141	123,660	1	0.43	3
100	50	100	100	100	20,113,461	99	99	19,866,141	247,320	1	0.43	3
100	75	100	100	100	20,202,752	100	99	20,023,652	179,100	1	0.28	2
100	100	100	100	100	20,262,452	100	99	20,023,652	238,800	1	0.28	2
100	125	100	100	100	20,322,152	100	99	20,023,652	298,500	1	0.28	2
100	150	100	100	100	20,381,852	101	98	20,023,652	358,200	2	0.28	2
100	175	100	100	100	20,441,552	101	98	20,023,652	417,900	2	0.28	2
100	200	100	100	100	20,501,252	101	98	20,023,652	477,600	2	0.28	2



	25%	50%	75%	100%	125%	150%	175%	200%
Fixed Cost	123,660	247,320	179,100	238,800	298,500	358,200	417,900	477,600
Transportaion Cost	19,866,1	19,866,1	20,023,6	20,023,6	20,023,6	20,023,6	20,023,6	20,023,6
Min z	19,989,8	20,113,4	20,202,7	20,262,4	20,322,1	20,381,8	20,441,5	20,501,2

Figure 7. Comparison Of Fixed Cost, Transportation Cost And Min Z

Figure 7 illustrates the fixed cost ratios of opening warehouses at 25%, 50%, 75%, 100%, 125%, 150%, 175%, and 200%. The figure demonstrates the response of transportation cost, fixed cost, and the objective function to changes in the fixed cost ratio. Specifically, it provides a comparison between fixed costs, transportation costs, and the minimum objective function value (min z) based on variations in the fixed cost ratio.

The figure reveals that the min z value and fixed costs exhibit a parallel increase, indicating a direct relationship. Furthermore, it is observed that as the fixed cost increases, the transportation cost tends to decrease, suggesting an inverse relationship between these two factors.

4.2.3. Full Truckload (FTL) Rate

Table 5 presents the Full Truckload (FTL) rates. In this scenario, some of the loads are directed to the warehouse, while others are delivered directly to customers. We analyzed the variations in the FTL ratios, which range from 25% to 200%, to observe their impact on the system.

Table 5. Full truckload rates

Depot Cap Ratio	Fixed Cost Ratio	FTL Ratio	Demand Ratio	Transportation Cost Ratio	Min z	z%	TC/z %	Transportation Cost (TC)	Fixed Cost (FC)	FC/z %	Depot Ratio	Number of Depots
100	100	25	100	100	20,435,062	101	99	20,196,262	238,800	1	0.28	2
100	100	50	100	100	20,267,154	100	99	20,028,354	238,800	1	0.28	2
100	100	75	100	100	20,262,452	100	99	20,023,652	238,800	1	0.28	2
100	100	100	100	100	20,262,452	100	99	20,023,652	238,800	1	0.28	2
100	100	125	100	100	20,262,452	100	99	20,023,652	238,800	1	0.28	2
100	100	150	100	100	20,262,452	100	99	20,023,652	238,800	1	0.28	2
100	100	175	100	100	20,262,452	100	99	20,023,652	238,800	1	0.28	2
100	100	200	100	100	20,262,452	100	99	20,023,652	238,800	1	0.28	2

We kept the warehouse capacity ratio, fixed cost ratio, demand ratio, and transportation ratio constant throughout the analysis. In Table 5, the first column shows the warehouse capacity ratio, the second column contains the fixed cost ratio, the third column represents the Full Truckload (FTL) ratio, the fourth column displays the demand ratio, and the fifth column provides the transportation ratio. The minimum z values, representing the objective function, are listed in the sixth column. The seventh column shows the percentage impact on the objective function as the FTL ratio changes from 25% to 200%.

Additionally, we calculated transportation costs, fixed costs, and warehouse ratios. The eighth column shows the percentage of transportation costs relative to the objective function, with the absolute transportation cost listed in the ninth column. The fixed costs are presented in the tenth column, and the percentage of fixed costs relative to the objective function is shown in the eleventh column. The warehouse ratio is displayed in the twelfth column. Finally, the thirteenth column presents the number of warehouses opened as the FTL ratio changes between 25% and 200%.

To better interpret the results, we compared the transportation cost to the minimum z value and the fixed cost to the objective function value, expressing both as percentages for easier analysis. The changes in the full truckload ratio did not lead to significant differences in costs or the number of warehouses opened. This lack of variation suggests that the selected parameter values are close to reality and that the solution is likely optimal.

4.2.4. Customer's Demand Rates

Table 6 presents the customer demand rates, which were gradually varied from 25% to 200%. This change is shown in the fourth column. Throughout the analysis, the warehouse capacity ratio, fixed cost ratio, Full Truckload (FTL) ratio, and transportation ratio were held constant. The first column shows the warehouse capacity ratio, the second column contains the fixed cost ratio, the third column represents the FTL ratio, and the fifth column provides the transportation ratio. The minimum z values, representing the objective function, are listed in the sixth column. Column seven shows the percentage change in the objective function corresponding to changes in the demand ratio from 25% to 200%. The eighth column presents the percentage ratio of transportation cost to the objective function. Additionally, we calculated transportation costs, fixed costs, and warehouse ratios. The ninth column shows transportation costs, the tenth column displays fixed costs, the eleventh column provides the percentage ratio of fixed costs to the objective function, and the twelfth column lists the warehouse ratio. Column thirteen shows the number of warehouses opened based on changes in the demand ratio.

To better interpret the results, we compared the transportation cost to the minimum z value and the fixed cost to the objective function value, both expressed as percentages for easier analysis. When customer demand increases or decreases, the total costs change proportionally. Transportation costs also varied at the same rate as demand. For a demand ratio of 25%, one warehouse was opened, while for all other ratios, the number of warehouses remained constant at two.

Table 6. Customer's demand rates

Depot Cap Ratio	Fixed Cost Ratio	FTL Ratio	Demand Ratio	Transportation Cost Ratio	Min z	z%	TC/z %	Transportation Cost (TC)	Fixed Cost (FC)	FC/z %	Depot Ratio	Number of Depots
100	100	100	25	100	4,963,820	24	99	4,897,820	66,000	1	0.39	1
100	100	100	50	100	9,871,423	49	98	9,632,623	238,800	2	0.56	2
100	100	100	75	100	15,020,295	74	98	14,781,495	238,800	2	0.37	2
100	100	100	100	100	20,262,452	100	99	20,023,652	238,800	1	0.28	2
100	100	100	125	100	25,544,462	126	99	25,305,662	238,800	1	0.22	2
100	100	100	150	100	30,842,763	152	99	30,603,963	238,800	1	0.19	2
100	100	100	175	100	36,165,841	178	99	35,927,041	238,800	1	0.16	2
100	100	100	200	100	41,681,093	206	99	41,442,293	238,800	1	0.14	2

4.2.5. Transport Cost Rate

Table 7 presents the transportation cost ratios, which were varied between 25% and 200%. Throughout this analysis, the warehouse capacity ratio, fixed cost ratio, Full Truckload (FTL) ratio, and demand ratio were held constant. The first column presents the warehouse capacity ratio, the second column displays the fixed cost ratio, the third column shows the FTL ratio, the fourth column provides the demand ratio, and the fifth column contains the transportation cost ratio. The minimum z values, representing the objective function, are listed in the sixth column. The seventh column shows the percentage change in the objective function in response to variations in the transportation cost ratio. Additionally, transportation costs, fixed costs, and warehouse ratios were calculated. The eighth column presents the percentage ratio of transportation costs to the objective function, with transportation costs listed in the ninth column and fixed costs in the tenth column. The percentage ratio of fixed costs to the objective function is shown in the eleventh column, and the warehouse ratio is provided in the twelfth column. To better understand the meaning and variations in these values, we compared the transportation cost to the minimum z value. Similarly, we compared the fixed cost to the objective function, expressing both as percentages for easier analysis. The costs varied in proportion to the transportation cost ratio. When the transportation cost ratio reached 175% and 200%, the model tended to open an additional warehouse, which subsequently increased the fixed cost.

Table 7. Transportation cost rate

Depot Cap Ratio	Fixed Cost Ratio	FTL Ratio	Demand Ratio	Transportation Cost Ratio	Min z	z%	TC/z %	Transportation Cost (TC)	Fixed Cost (FC)	FC/z %	Depot Ratio	Number of Depots
100	100	100	100	25	5,244,713	26	95	5,005,913	238,800	5	0.28	3
100	100	100	100	50	10,250,626	51	98	10,011,826	238,800	2	0.28	3
100	100	100	100	75	15,256,539	75	98	15,017,739	238,800	2	0.28	3
100	100	100	100	100	20,262,452	100	99	20,023,652	238,800	1	0.28	3
100	100	100	100	125	25,268,365	125	99	25,029,565	238,800	1	0.28	3
100	100	100	100	150	30,274,278	149	99	30,035,478	238,800	1	0.28	3
100	100	100	100	175	35,260,387	174	99	34,765,747	494,640	1	0.43	2
100	100	100	100	200	40,226,922	199	99	39,732,282	494,640	1	0.43	2

CHAPTER 5: CONCLUSION

The logistics industry, as a vital component of the global economy, is increasingly gaining attention from both commercial developers and municipalities. The demand for new logistics and distribution facilities—such as warehouses, distribution centers, and transfer stations—has surged in various regions of Germany and across Europe (Cushmann and Wakefield, 2006). This rising demand highlights the importance for businesses to carefully consider location selection when establishing logistics centers. Factors such as land availability, land cost, infrastructure accessibility, and traffic volume significantly influence the placement of regional distribution centers or transfer warehouses. The strategic placement of these logistics centers can effectively alleviate traffic congestion and its associated consequences, offering mutual benefits to both businesses and governments (Wagner, 2010).

Transportation is a critical sector in the economic framework of the European Union. With a workforce comprising 5% of the population and contributing 7% to the GDP, it plays a fundamental role in ensuring the smooth functioning of the European economy. Establishing an efficient and sustainable transport infrastructure enables Europe to secure competitive advantages in the global market (Germany Federal Ministry for Digital and Transport, 2024).

In Germany, the logistics industry has witnessed significant growth in both freight volume and freight traffic performance over recent decades. This growth has contributed to the increasing importance of the logistics sector in terms of employment and its contribution to economic prosperity. Key factors driving this trend include the rise of logistics outsourcing and changes in the nature of goods being transported. German local and regional authorities are increasingly leveraging location marketing and land-use planning initiatives to attract logistics service providers to commercial real estate zones (Rolko and Friedrich, 2017). The primary objective of these efforts is to foster job creation, which, in turn, enhances local tax revenue (Wagner, 2010).

Germany boasts the most extensive highway network in Europe, spanning 13,200 kilometers as part of a broader road network totaling 230,082 kilometers. In addition, Germany's waterways extend 7,675 kilometers, and the operated railway lines measure 37,775 kilometers. Complementing this vast transportation infrastructure is a sophisticated energy and communication network, which collectively facilitates prompt and efficient product distribution. These factors have enabled Germany to maintain its leading position in the logistics sector both in Europe and globally.

Germany consistently ranks at the top of the "Logistics Performance Index (LPI)" released by the World Bank, with the 2018 edition acknowledging Germany's strength in areas such as customs clearance, infrastructure, international shipments, logistics competence, cargo tracking and tracing, and timely delivery.

Hamburg stands out as a key logistics hub in Germany, employing approximately 315,000 individuals in the sector. The Port of Hamburg is the second largest in Europe and the most active logistics center in Germany. Despite the negative impacts of the pandemic on other sectors, the logistics industry experienced substantial growth in transaction volumes and revenues both within Germany and internationally. The sector recorded a 5% increase in turnover in 2021, reaching €293 billion and surpassing the previous year's figures (Ministry of Commerce, International Agreements, and the European Union General Directorate, 2022).

A company engaged in intermodal partial and full-load cargo transportation between Türkiye and Germany identified several candidate warehouses in Germany to reduce costs rather than managing direct delivery of various cargos. The study aims to identify the most optimal subset of warehouses among these alternatives. A mathematical programming model was employed to address this problem. The model determines the optimal decisions for opening warehouses, selecting transportation modes, managing flows between modes and warehouses, and determining the final delivery methods. The objective of the model is to minimize total transportation and warehouse leasing costs. Randomly generated datasets were utilized in this study.

The findings suggest that opening two of the candidate warehouses would be the optimal solution, minimizing both warehouse and transportation costs. The results from the model align with similar studies in the literature, demonstrating how opening two warehouses can significantly reduce both warehouse-related costs and transportation expenses. These findings underscore the critical role that warehouse layout decisions play in shaping supply chain costs. According to the model's outputs, the establishment of two strategically positioned warehouses is the most cost-effective course of action, ensuring both minimal expenses and enhanced operational efficiency. These warehouse locations were selected based on their proximity to demand points and transportation hubs.

The model also optimizes the usage of different transportation modes to minimize costs. Rail transportation, for instance, offers low-cost and energy-efficient solutions for moving large volumes of cargo over long distances. Additionally, rail transport generates fewer carbon emissions compared to road transport, thereby enhancing environmental sustainability. By offering low transportation costs, particularly over long distances, rail transportation helps reduce overall costs. Its lower carbon emissions and energy consumption further contribute to sustainable practices. Moreover, rail transport is less affected by traffic and weather conditions compared to road transport, enhancing its reliability.

Maritime transportation, particularly for large-volume and heavy-load international shipments, stands out as a cost-effective and energy-efficient mode. Maritime transport provides low transportation costs for substantial cargo volumes, promotes environmental sustainability through high energy efficiency, and offers flexibility and capacity for handling large loads (Zhang et al., 2024).

Li et al. (2024) also highlight that road transportation offers flexible and fast delivery, particularly for final deliveries, ensuring that customer demands are promptly and effectively met. It provides door-to-door delivery solutions that are both flexible and customer-oriented, contributing to faster deliveries over shorter distances and thus improving customer satisfaction. Road transportation also ensures accessibility in both urban and rural areas.

This thesis examines a corporation involved in intermodal transportation from Türkiye, a developing country, to Germany, a developed country. At each stage of this thesis, data most representative of real-world scenarios were employed to address practical logistical challenges. The integration of different transportation modes was achieved through an intermodal transportation approach. Fuel costs per kilometer for each vehicle were calculated based on the latitude and longitude coordinates of the locations. Lower and upper bounds were set for transportation modes, storage, and Full Truckload (FTL) operations to ensure a more accurate outcome.

This integration has significantly improved the efficiency of logistics processes, reducing both transportation costs and environmental impacts. Optimizing the transitions between different transportation modes further enhanced logistical efficiency while reducing costs. The most appropriate mode combinations were determined by considering transitions between modes and transportation times.

Intermodal transportation has proven to be an effective strategy for reducing transportation costs and minimizing environmental impacts. The capacities and pricing of each prospective warehouse were assessed based on real-world warehouse listings. Flows between opened warehouses and final delivery methods were optimized, ensuring the efficient utilization of warehouses and timely fulfillment of customer demands. The use of trucking for final deliveries allowed customer demands to be met flexibly and promptly. This study demonstrates the impact of optimizing warehouse layout decisions and transportation modes on overall logistics and supply chain management. Notably, the strategic use of intermodal transportation emerges as a key approach to reducing costs and promoting environmental sustainability

CHAPTER 6: LIMITATION

Regarding storage and transportation, multiple risk factors come into play. Some of these are risks that may occur on the road. For example, these may be weather conditions and climatic problems. Although opening a warehouse and shipping some of the loads from the warehouse reduces costs, it also creates a risk factor. Storage and handling damage are examples of these. We solved this problem without setting any time limit, which may be one of the most fundamental shortcomings. It may be a more complex problem to solve in a way that reaches the customer in the time frame he needs. Determining these risks in order of importance and the measures to be taken for them may create a cost element. This may actually seem like a shortcoming, but since we made decisions at the strategic level, these operational due dates were examined in terms of cost.

In addition, at another point that can be improved, the solution can be examined in terms of environmental friendliness and sustainability. The German Supply Chain Act covers large companies and public institutions operating in the supply chain. These companies are required to take appropriate measures to prevent human rights violations and environmental damage. The law states that companies' activities in the supply chain will be made legally binding, and sanctions will be imposed in case of violations. The aim of the law is to increase the responsibility of companies to reduce environmental pollution and ensure sustainability (Germany Federal Ministry of Labour and Social Affairs, 2024). Thus, the sustainable part of this study can be improved. These issues may be among the aspects of this thesis that are open to development.

Intermodal freight networks are critical to global logistics and facilitate efficient transportation. Transportation of cargo in containers by integrating different transport modes. However, such integration of intermodal freight transportation exposes networks to various disruptions and may lead to deterioration in transportation capabilities. Like this, vulnerability assessment and mitigation for intermodal freight transportation networks may be another point of this thesis that needs to be developed in the future.

Our study offers some suggestions for future research when evaluated regarding sustainability and environmental impacts. Verifying and increasing the validity of the model using different scenarios and larger data sets. Analyzing the effects of logistics processes on environmental sustainability in more detail by conducting an environmental impact assessment is crucial for sustainable policies in the logistics sector. Further research for its development and implementation is needed. These policies should include strategies that support environmental sustainability and increase energy efficiency.

The details enable us to provide a more comprehensive and in-depth analysis of sustainability and environmental impacts. Sustainable logistics and minimizing environmental impacts are a critical issue for both academic studies and practical applications and will increase the value of work.

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