MAY 2023

M.Sc. in Industrial Engineering

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REPUBLIC OF TÜRKİYE

GAZİANTEP UNIVERSITY

GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

ELECTRICAL AND ELECTRONICS GOODS WASTE MANAGEMENT AND OPTIMAL WAREHOUSE LOCATION SELECTION IN TURKEY

M.Sc. THESIS

IN

INDUSTRIAL ENGINEERING

BY

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Prof. Dr. Serap ULUSAM SEÇKİNER

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May 2023

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Ayşe KÖKYILDIRIM

ABSTRACT

ELECTRICAL AND ELECTRONICS GOODS WASTE MANAGEMENT AND OPTIMAL WAREHOUSE LOCATION SELECTION IN TURKEY

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May 2023
72 pages

The amount of electronic waste is increasing gradually with the rapid and unconscious consumption of technological products today in Turkey. Within the scope of this study, the current situation of electrical and electronic goods in Turkey has been addressed. The registered collection rate of e-waste formed in our country is low. The main reason for the low collection rates is the unregistered and uncontrolled collection of e-waste. These wastes need to be recovered into the economy. Without a suitable collection structure, it is difficult to recover the resulting electronic waste. In this study, electronic waste (e-waste) that is not collected properly and inconsistently occurred is addressed. It is aimed to establish suitable warehouse locations in the districts close to the organized industrial zones covering certain provinces with developed electronic waste applications and industries in Turkey. There are 28 demand points in the study. To provide the most appropriate service to these demand points, the p-median problem was applied as a location-allocation model. The IBM OPL CPLEX program was used to determine the selection and number of warehouse locations to be opened. As a result of the optimization, suitable warehouse locations to be opened have been decided. It was decided that the optimal number of warehouses was 5. It is difficult for society to leave their wastes from their homes to places where warehouses are planned to be established. It is planned to create waste collection boxes in central places so that all provinces will receive service. The waste collection boxes formed can receive services from the opened warehouse locations.

Keywords: P-median Problem, Electronic Waste (E-waste), Warehouse Selection, Mathematical Model, Waste Collection Boxes, Optimal Solution

ÖZET

TÜRKİYE’DE ELEKTRİKLİ VE ELEKTRONİK EŞYA ATIK YÖNETİMİ VE OPTİMAL DEPO YER SEÇİMİ

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Mayıs 2023
72 sayfa

Günümüzde Türkiye’de teknolojik ürünlerin hızlı ve bilinçsiz tüketimi ile elektronik atık miktarı giderek artmaktadır. Bu çalışma kapsamında, Türkiye’de elektrikli ve elektronik eşyaların mevcut durumu ele alınmıştır. Ülkemizde oluşan e-atıkların kayıtlı toplama oranı düşüktür. Toplama oranlarının düşük olmasının ana sebebi kayıtsız ve kontrolsüz şekilde toplanan e-atıklardır. Bu atıkların ekonomiye geri kazandırılması gerekmektedir. Uygun bir toplama yapısı olmadan, ortaya çıkan elektronik atıkları geri kazanmak zordur. Bu çalışmada, usulüne uygun toplanmayan ve tutarsız şekilde ortaya çıkan elektronik atıklar (e-atık) ele alınmıştır. Türkiye’de elektronik atık uygulaması ve sanayisi gelişmiş belirli illeri kapsayan organize sanayi bölgelerine yakın ilçelerinde uygun depo yerlerinin kurulması amaçlanmıştır. Çalışmada 28 adet talep noktası vardır. Bu talep noktalarına en uygun hizmetin sağlanabilmesi için P-medyan problemi lokasyon tahsis modeli olarak uygulanmıştır. Açılması gereken depo yerleri seçimi ve sayısını belirlemek için IBM OPL CPLEX programı kullanılmıştır. Optimizasyon sonucunda açılması düşünülen uygun depo yerlerine karar verilmiştir. En uygun depo sayısı 5 olduğuna karar verilmiştir. Toplumun atıklarını evlerinden, depo kurulması öngörülen yerlere bırakması zordur. Tüm iller hizmet alacak şekilde merkezi yerlerde atık toplama kutularının oluşturulması planlanmıştır. Oluşan atık toplama kutuları ise açılan depo yerlerinden hizmet alabilmektedir.

Anahtar Kelimeler: P-medyan Problem, Elektronik Atık (E-atık), Depo Seçimi, Matematiksel Model, Atık Toplama Kutuları, Optimal Çözüm

''Dedicated to my family''

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Prof. Dr. Serap ULUSAM SECKİNER for her guidance and support throughout the study. I am thankful for her encouragement and motivation.

I would like to thank my jury teachers Prof. Dr. Eren ÖZCEYLAN and Asst. Prof. Dr. Yunus EROGLU, during my graduate education for his help and support.

I would like to thank, the TUBİSAD institution and the personnel working in this authorized institution, who helped me find the data in this study.

I would like to express my endless thanks and respect to my dear friend Orhan Celik, who has not spared his help throughout my studies.

I would like to thank my friend Cem Cuhadar, during my graduate education for his help and support.

I would like to thank my family for their patience and support during my intensive studies during my graduate education.

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LIST OF ABBREVIATIONS

WEEE	Waste Electric and Electronic Equipment
EEE	Electric and Electronic Equipment
E-WASTE	Electronic Waste
MEU	Ministry of Environment and Urbanization
ELDAY	Electrical and Electronics Recycling and Waste Management Association
AGID	Lighting Equipment Manufacturers Association
TUBISAD	Informatics Industry Association
EU	European Union
IZAYDAS	Izmit Waste and Residues Treatment, Incineration and Evaluation
CRT	Cathode Ray Tube
PCB	Printed Circuit Board
HCFC	Hydrochlorofluorocarbons
HFC	Hidroflorokarbon
CPU	Central Process Unit
EVFT	Education Volunteers Foundation of Turkey
PTO	Post and Telegraph Organization
EAGD	Electronic Waste Recycling Support Association

CHAPTER 1

INTRODUCTION

1.1 Introduction

The concept of e-waste was first published in Turkey on May 22, 2012, with the Waste Electrical and Electronic Good Control Regulation. All electronic products that we do not want to use, obsolete or not in working condition are called 'e-waste' or 'electronic waste'. Electrical and electronic goods (EEE); are products with areas of use such as computers, mobile phones, televisions, white goods, and small household appliances. The amount of electronic waste varies according to the economic and social welfare levels of the countries. EEEs turn into WEEE at the end of their useful life. Therefore, WEEEs need to be managed by legislation [10]. In Turkey, the annual estimated amount of e-waste is 500 thousand tons. Turkey ranks 17th among the countries that produce the most e-waste. The amount of e-waste per capita is related to the welfare level of the countries. For this reason, while the amount of waste per capita corresponds to 29 kilograms in countries with high national income, this figure is 6.5 kg in Turkey. While e-waste management is carried out, it includes all the activities of prevention, reduction, reuse of waste, separating according to type, accumulation, collection, temporary warehouse, transportation, intermediate warehouse, recycling, disposal, monitoring after disposal, control, and inspection processes [1].

1.2 Importance of E-wastes

E-waste management is the most challenging issue in our country as it is in the world. Today, it is important to properly manage electronic waste. The environment and human health are among the main reasons for the proper management of e-waste [19]. All raw materials (gold, copper, nickel) used in the production of electrical and electronic goods highlight the economic value [14].

Figure 1.1 E-waste Categories

1.3 Electrical and Electronic Goods Harmful Substances Found

Dozens of harmful elements, which are not found in any of the goods around us, are located in electronic goods. Computer monitors and television screens contain about 1-4 kg of lead. Monitor glasses contain twenty percent lead. There are heavy metals, CFC gases, oil, and some harmful pollutants that delay brominated combustion in electrical and electronic goods waste. Therefore, improper recycling of important metals such as mercury, lead, and cadmium harms human and environmental health. Because of the burning of electrical and electronic wastes in open areas, their uncontrolled separation and irregular storage, anti-burning agents mix with the environment and harm human health. The harms of some substances in these electronic wastes to human health are as follows: [14]

Mercury: Brain Damage, Liver Damage

Lead: Brain Damage, Nervous System Damage

Chromium: Eye Diseases, DNA Damage

Cadmium: Lung Cancer, Kidney Disorders

BFR (Bromine Flammable): Hormonal Disorders

Electronic goods waste is an important factor that needs to be regained in the economy. This is because of the valuable ingredients in it. If electronic waste is not to be used, the last step to be done is to dispose of it and burn it. However, during this process, it causes the release of many carcinogenic substances into the atmosphere.

1.4 Waste Management of Electrical and Electronic Goods in Turkey

The population in Turkey is increasing rapidly. For this reason, it is predicted that the cities of the future will have a high population. The rapidly increasing population also affects waste production. According to a report comparing Southeastern European countries, including Turkey, as the urban population increases, there is an increase in waste generation (MBB, 2015). For these cities to respond to production, waste management must be done well. Turkey lags far behind Japan in the consumption of electronic goods. However, with the increase in purchasing power and the sales of global brands in Turkey, Turkish consumers' interest in technology has increased. Therefore, the Turkish technology market has become a rapidly growing market position [19].

In the Regulations in Turkey, manufacturers of electrical goods, municipalities, organizations that process electrical and electronic equipment waste, and consumers have various duties. The biggest responsibility for establishing a system for the management of e-waste falls to the manufacturers who put electronic goods on the market. These manufacturers are responsible for establishing a system for the collection and processing of electronic goods waste and meeting the costs of the established system. Distributors that sell electrical and electronic products are responsible for keeping a waste collection box for the collection of waste, raising awareness of the consumer, and giving these collected wastes to established systems.

When we look at the WEEE producers registered in the system in Turkey, it is seen that the highest number of producers is percent 82.2 in Istanbul (Ünal, 2012). Therefore, Istanbul is one of the most important cities in Turkey in terms of controlling WEEE as a big city where consumption is also very intense.

In the principles of the WEEE Control Regulation, the waste hierarchy is recommended as reuse, recycling, and recovery, respectively. If it is possible to use the resulting waste, reuse should be preferred. It has been stated that companies with environmental licenses can dispose of electronic wastes that cannot be reused, recycled, or recovered. The image below shows the waste hierarchy [14].

Figure 1.2 Waste Hierarchy

The responsibility for e-waste collection falls on the municipality. Three methods are applied for municipalities to collect e-waste. Collection in waste collection centers, waste accumulation points, and door collection methods. These methods are used mixed by municipalities [19].

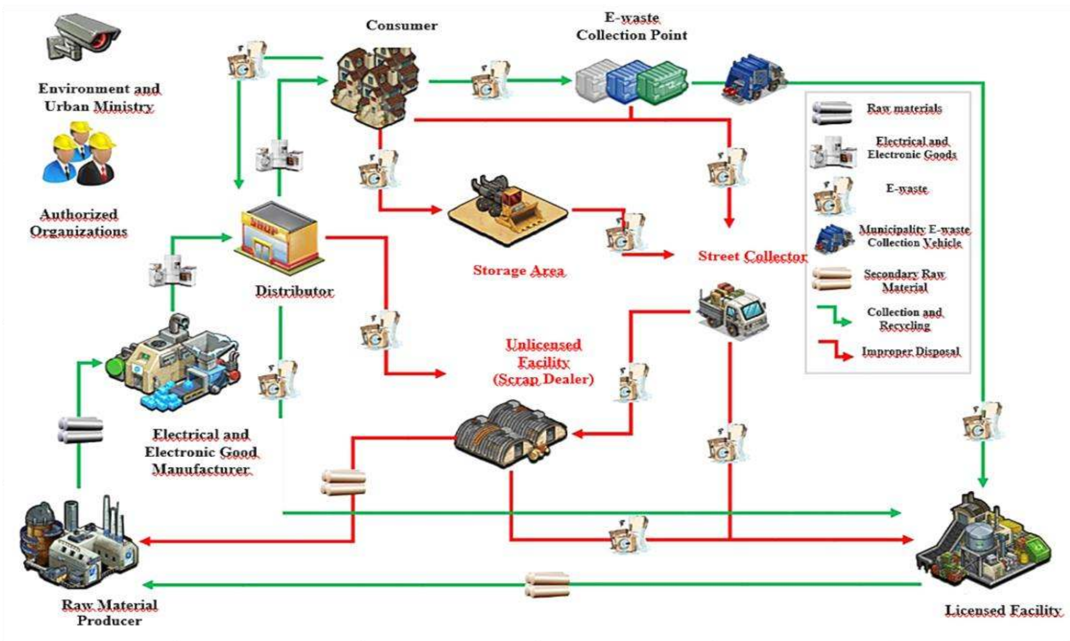

Figure 1.3 E-waste Cycle Predicted by Legislation [19].

1.5 Predictions of E-waste Amounts in Turkey

The amount of EEE used is very important for the estimation of the amount of WEEE. Although the actual amount of waste cannot be reached based on the production information, this information has the feature of giving an idea about the amount of waste that may occur in the future.

It is critical to know and estimate the total amount of electrical and electronic goods correctly and to calculate the collection targets in the regulation to be revised for these estimates. According to the previous study, in 2017, the total amount of electrical and electronic goods in Turkey was calculated as 777 thousand tons, and the average for 2014, 2015 and 2016 was calculated as 750 thousand tons (EC, 2014).

According to a report comparing Southeastern European countries, including Turkey, as the urban population rate increases, waste generation also increases (MBB, 2015). In the commission report, it is estimated that the total amount of e-waste in Turkey will reach 672 thousand tons by 2024. In general, the largest category of e-waste is small household appliances.

According to the report prepared by the European Union in 2014, it is estimated that Turkey's e-waste amount will increase percent 12 to 2024 (Magalini, et al., 2014).

The e-waste amounts in the table below are taken from the hazardous waste statistics section of the MoEU (Ministry of Environment and Urbanization).

Table 1.1 Annual e-waste amounts in Turkey [21].

Years	Waste Electrical and Electronic Equipment Amount (ton)
2015	32,029
2016	39,394
2017	37,326
2018	37,517
2019	46,360
2020	67,153

Tubisad was founded in 2015 by the T.R. It has been appointed by the Ministry of Environment, Urbanization and Climate Change as the authorized institution of Household Waste Electrical and Electronic Equipment (WEEE) in the category of 3rd Category TV-Monitors and 4th Category IT, Telecommunication and Consumer Equipment. In this process, as the authorized institution, the collection studies of electrical and electronic goods continue. Since the data before the 2018 and 2019 pandemics are more instructive, the data on the monthly collection amounts of Tubisad 3rd and 4th category household electrical and electronic goods wastes are given in the table. These data are household WEEEs collected as a result of Tubisad studies [22].

Table 1.2 Household WEEE collected monthly by Tubisad

Months	**2018**	**2019**
January	6,061.73	14,982.35
February	18,277.20	19,028.40
March	10,707.00	47,114.45
April	20,189.28	106,741.60
May	33,572.10	29,609.40
June	6,671.00	7,219.10
July	13,736.60	30,054.73
August	8,919.20	9,185.73
September	14,496.43	19,607.58
October	13,737.00	21,189.96
November	23,343.53	9,143.59
December	66,231.25	65,256.83
Total WEEE Amount (kg)	**235,942.32**	**379,133.72**

According to the data received from Tubisad, the total amount of waste created by household electrical and electronic goods in categories 3 and 4 in 2019 increased by 60.69 percent compared to 2018 [22].

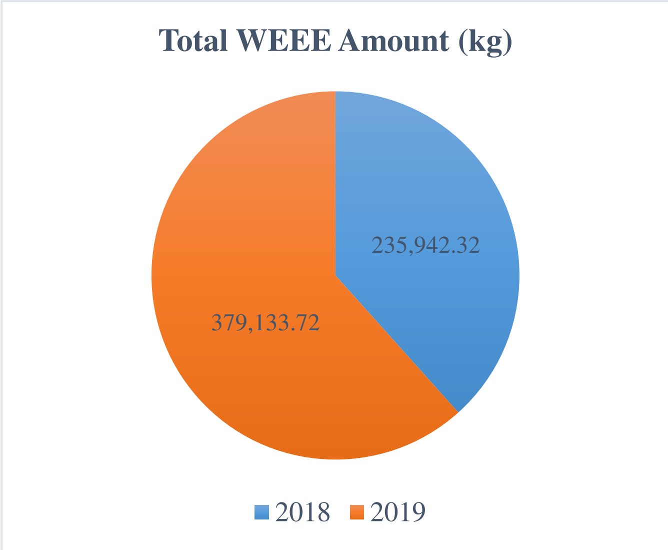

Figure 1.4 Distribution of Total WEEE amount

1.6 Evaluation of Electrical and Electronic Goods Waste In Turkey

In Turkey, good developments have started to be experienced in some organizations recently to evaluate the waste of electronic goods, but this is not enough. These organizations continue their activities to evaluate electronic goods waste. The organizations responsible for the collection, recycling, and recovery of electronic goods waste are as follows: Electrical and Electronics Recycling and Waste Management Association (ELDAY), Lighting Equipment Manufacturers Association (AGID), Informatics Industry Association (TUBISAD), and electronic waste recycling firm in Kocaeli Exitcom Recycling; It recycles computers, mobile phones, tablets, end-of-life electrical and electronic goods by European Union (EU) standards. Turk Telekom, “Bring Your E-waste, Leave a Greener World for Tomorrow!” The campaign has contributed to recycling by collecting 18 tons of electronic waste in 3 years. Those who use electronic goods generate e-waste. Developed countries occur in most of the e-waste and they are trying to solve the e-waste problem by exporting them to Asian and African countries [3].

1.6.1 Electrical and Electronic Goods Waste Recycling Process in Turkey

In society, people buy different electrical and electronic products to meet their needs. After using electrical and electronic products, if the products become waste, they should be recycled. While 1-5 g of gold is obtained from 1 ton of soil, 230 g of gold and 3.5 kg of silver are obtained from 1 ton of mobile phone waste. Therefore, these wastes should be recycled. The amount of electrical and electronic waste foreseen in Turkey varies from year to year. According to the researchers, between 10.000 – 25.000 tons of annual electrical and electronic waste, corresponding to percent 2.5 of it is recycled [33]. When electrical and electronic goods are managed appropriately, valuable and important metals such as copper, silver, gold, etc., can be recovered to the economy. Automation has been started for the recycling of e-waste, which is mainly recycled manually in our country. WEEE management and recovery; requires the creation and management of a circulation system from a collection of transportation, from storage to processing, and from final disposal to reporting [23].

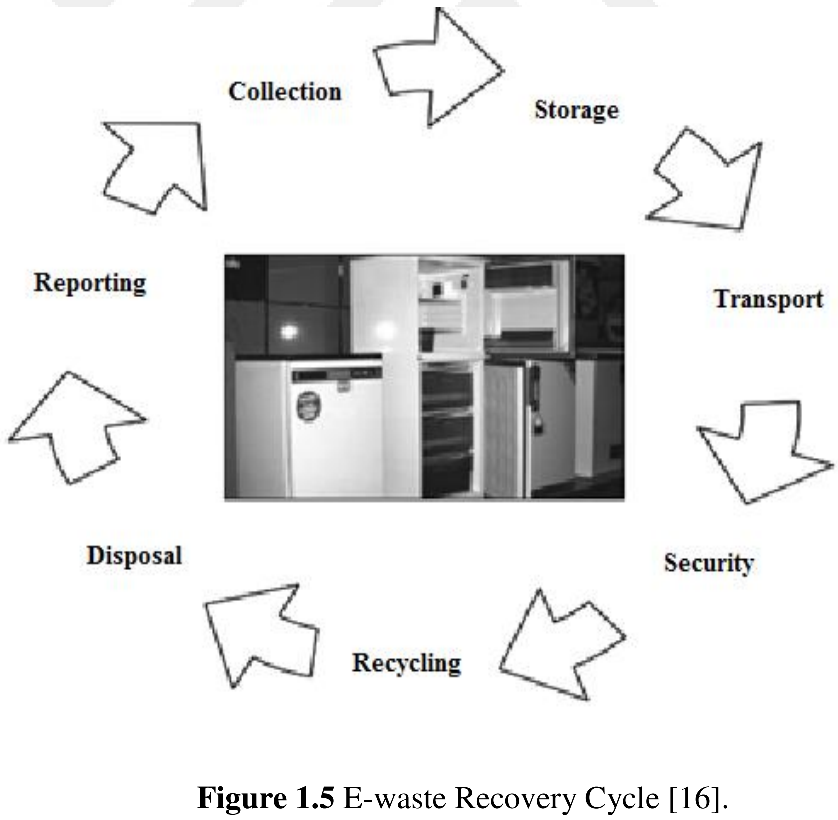

Figure 1.5 E-waste Recovery Cycle [16].

The stages of electrical and electronic goods in Turkey are as follows: Collection, storage, destruction, recycling, reporting, transportation, separation, and finally disposal. Many organizations perform the collection of electrical and electronic goods waste. These wastes should be stored in special plastic boxes and under appropriate conditions during storage. Separated parts are also placed in separate sections. In addition, some of these wastes can turn into fertilizer. During the disposal of these wastes, municipal institutions such as IZAYDAS and licensed private companies can also fulfill them. After this process, gold, copper, iron, etc. materials are recovered into the economy. While these processes are being carried out, the recycling and disposal rates are reported to the companies and recorded. While transporting electrical and electronic goods, it is carried out on vehicles such as drivers, personnel, etc., which have the Hazardous Waste Transport Certificate. During the receipt of these wastes, the relevant forms are prepared and submitted to the Provincial Directorate of Environment and T.C. Relevant notifications are made to the Ministry of Environment and Forestry. While the materials are being unloaded and pre-separated, lighting devices such as batteries and fluorescent lamps are separated. The remaining waste is stored to enter the production process. At the last disposal stage, the batteries are sent to the relevant battery recycling facilities. Batteries are sent to the Turkish Battery Importers and Manufacturers Association. Fluorescent lighting devices, CRT tubes, and monitors that emerge in the pre-separation process are sent to authorize disposal organizations for disposal.

Electronic goods consist of components such as batteries, circuit boards, cathode ray tubes, and plastic cases. Percent 49 of e-waste is metal, percent 33 is plastic materials, and percent 12 is cathode ray tubes. For this reason, e-waste needs to be recycled or destroyed differently. In the recycling process of e-waste, it is first determined whether the device or the parts of it can be reused. After the components that can be reused are determined, those that need to be recycled are separated into small parts. Ferromagnetic metals, non-ferromagnetic metals, and plastic components in e-waste are then separated from the remaining parts. These materials are converted into the final product using recycling methods. Recycling should be considered as a health and environmental recovery method rather than economic gain [19].

Recovered raw material rates according to e-waste categories are given in the table.

Table 1.3 Recovered Raw Material Rates by E – Waste Categories

Equipment Categories	Iron	Non-Iron Metals	Cam	Plastic	Other
Great domestic appliances	%61	%7	%3	%9	%21
Small domestic appliances	%19	%1	%0	%48	%32
IT equipment	%43	%0	%4	%30	%20
Telecommunication	%13	%7	%0	%74	%6
Tv radio etc.	%11	%2	%35	%31	%22
Rechargeable and Gas Lamps	%2	%2	%89	%3	%3

Table 1.4 Recycling rates in countries (TSKD, 2017)

Countries	Recycling rates (%)
Sweden	62,6
Japan	24
China	21
USA	14
Turkey	5

According to the research conducted, when we compare the recycling rates of countries, the country with the lowest percentage is Turkey.

Figure 1.6 Turkey's First Electronic Waste Recycling Facility/Tubitak

1.7 EEE Waste Coding System

The waste consists of six-digit code. It is obligatory to use these codes fully in all studies on waste.

Those marked with (*) are hazardous waste.

Waste Management Regulation (2015) collects e-waste types under 9 groups.

Table 1.5 EEE Waste Codes [24].

EEE Waste Codes	Definition
160209*	Transformers and capacitors containing PCBs
160211*	Discard equipment containing chlorofluorocarbon, HCFC, HFC
160212*	Discarded equipment containing free asbestos
160213*	Discard equipment containing dangerous parts other than 16 02 09 to 16 02 12

Table 1.5 EEE Waste Codes (Cont.)

EEE Waste Codes	Definition
160214	Discard equipment other than 16 02 09 to 16 02 13
200121*	Fluorescent lamps and other mercury-containing waste
200123*	Discarded equipment containing chlorofluorocarbons
200135*	Discarded electrical and electronic equipment containing dangerous parts other than those mentioned in 20 01 21 and 20 01 23
200136	Discard electrical and electronic equipment other than 20 01 21, 20 01 23 and 20 01 35

Waste management application was used to calculate the amount of recovering and disposal of electronic goods by province. The waste management application of waste producers reports the recovery and disposal amounts of electronic wastes in Excel according to waste codes and provinces. This application consists of data for the years 2015-2019. For this reason, the most recent year, 2019, was taken as a basis. Calculations were made on a provincial basis and according to electronic waste codes.

Figure 1.7 Waste Management Application

The data set was created by considering the electronic waste management application in Turkey, the provinces with developed industries and a population of more than 500,000. There are 28 provinces in total. Since the electronic waste recovery, and disposal amounts included in the waste management application of waste producers are between 2015-2019, the year 2019 is taken as the basis.

Table 1.6 Population Amounts

Provinces	Population
Adana	2,237,940
Mersin	1,840,425
Hatay	1,628,894
Antalya	2,511,700
Izmir	4,367,251
Manisa	1,440,611
Denizli	1,037,208
Mugla	983,142
Istanbul	15,519,267
Kocaeli	1,953,035
Bursa	3,056,120
Sakarya	1,029,650
Gaziantep	2,069,364
Diyarbakir	1,756,353
Ş.urfa	2,073,614
Mardin	838,778
Ankara	5,639,076
Konya	2,232,374
Kayseri	1,407,409
Eskisehir	887,475
Trabzon	808,974
Samsun	1,348,542
Ordu	754,198
Zonguldak	596,053
Van	1,136,757
Erzurum	762,062
Malatya	800,165
Elazıg	591,098

Studies on electronic goods waste are carried out, especially in provinces such as Istanbul, Kocaeli, and Bursa, where industrialization and population are concentrated. These provinces are managed more by the principles of electronic waste management [24]. The other parts of the study are as follows: The problem discussed in the problem definition section is included. In the literature review section, previous studies are included. In chapter 4 of the study, a mathematical programming model of the p-median problem is proposed and the datasets used in the study and the application are mentioned. Chapter 5 includes the findings. In the last section, there are conclusions and recommendations.

CHAPTER 2

PROBLEM DEFINITION

In our country, it is difficult to accurately know and estimate the total amount of electrical and electronic goods waste. There is no coordination between the Ministry of Environment and Urbanization and other institutions during in the talks held. Because the data is not open to the stakeholders, the regulation was insufficient in implementation. There is no regularly updated e-waste database. The total number of electrical and electronic goods manufacturers in Turkey is not known. For this reason, statistics on e-waste are confidential. The unregistered rate in the management of e-waste is high in our country. The reason why the collection rates are variable and not excessive is the unregistered and uncontrolled collection of e-waste.

Electronic goods waste is emerging as a new problem in the world because it is in harmful substances with advancing technology and our increasing consumption speed. Electronic products are produced every year by spending billions of euros. However, these products are thrown away after being used for a certain period. When we consider Turkey, an average of 500 thousand tons of electronic waste is occurring every year. This number is increasing by 10% every year. The amount of electronic goods waste processed in Turkey is very low compared to the total amount of electronic goods placed on the market. The reason for this low is the unregistered and uncontrolled collection of electrical and electronic goods waste. Scrap dealers and some informal businesses collect electronic goods waste unregistered. In addition, they process these wastes in their way. For this reason, the registered collection rate is low. These operations harm the environment and human health. In addition to the low collection rates, the number of e-waste collection centers and warehouse locations is also a problem in reaching the collection targets. Without an appropriate collection structure, it is difficult to recycle the resulting e-waste [19].

CHAPTER 3

LITERATURE REVIEW

There are many applied studies in the literature on warehouse location selection problems. However, even though electrical and electronic waste problems have become widespread throughout the world, it is observed that the problem of choosing a place for electronic goods waste is not sufficiently covered in the literature. In the study, a selection was made from the previous studies in the literature to reach the latest and most up-to-date information. These studies, which involve applications, are explained in detail below.

With the increase in technological developments, academic studies have gained momentum. Gundes et al. (2023) aimed to economy recover precious metals from ceramic processors (CPU) and mobile phone cards in computers. An economical method has been used in the recovery of life is out of the CPUs and phone cards. These methods are hydrometallurgical, pyro metallurgical and physical separation methods. In this process, he measured the amounts of precious metals with ICP-OES. He has approximately determined the gold ratios found in CPU and phone cards [37]. Cavdar et al. (2023) asked consumers to write down why the electrical and electronic products they use are of good quality or not. He evaluated the survey data of 191 participants. Analyzed in the MAXQDA 2022 program. As a result, he identified the products and brands most evaluated in terms of performance, usability, and quality [38]. Liu et al. (2023), present a global solution for the recycling of electronic waste in this study [39]. Singh et al. (2022) created a decision-making model. The study tries to decide on the optimum e-waste collection options in a particular region [41].

Sariyar et al. (2021) conducted a survey study of 100 people in the Bahcelievler neighborhood, which was selected as a pilot area in the city center of Samsun. The aim of the survey study is to determine the electrical and electronic goods consumption behaviors and waste awareness levels of the people living in the neighborhood. According to the survey results, people are aware of e-waste. However, the public should be informed about the content of e-waste and how to dispose of e-waste by the legislation [1]. Kara et al. (2021), this study carried out on the rail system. They developed a solution to the problem of determining the optimum number of stations and station location of the metro line to be built in the Gebze and Darıca districts with cluster coverage and alternative service level p-median model [2]. Melek et al. (2020), a mathematical model has been created to decide which of the maximum 10 selected cities to establish recycling centers for wastes coming from electronic waste collection centers in 38 cities in Turkey. In the study, it was aimed to minimize the installation, operational, and fixed costs of the recycling facility. The optimum facility location was determined by entering the data into the GAMS program. It was decided to establish the proposed recycling facility in Konya [3]. Acma etc. (2020), smartphones are changed approximately every two years in our country. The amount of precious metals in these products is high. In the study, the current situation analysis of electronic waste was made. It has been taken into account how much benefit these wastes going into the garbage can provide to the country's economy if the right waste awareness is formed [40]. Ersen et al. (2020) tried to determine the most suitable dealer locations in various provinces of Turkey for the company operating in the automotive sector. In the study, the problem of p-median facility location selection is discussed. A mathematical model has been proposed that aims to minimize the distance and the amount of carbon emissions. The company has been given the best plant location selection suggestions that take into account environmental sensitivity [4]. Sentürk (2019) conducted a survey study on 100 random people living in the Sivas city center. They met on the street with 23% of the participants, at home with 42%, and at the workplaces with 35%. The aim of the survey study is to determine the awareness level and behaviors of people about e-waste. As a result, most of the participants are aware of the danger of e-waste. However, they do not know what the method is or the legislation to get rid of these wastes. For this reason, it is understood that they will support the recycling of electrical and electronic equipment wastes in the process of informing consumers [5].

Kaya et al. (2018) compared the regulation on electronic waste in our country and the regulation in other countries. He focused on which projects and research should be done on this subject in Turkey. He made various suggestions about electrical and electronic wastes [6]. Alver et al. (2018), a multi-purpose mixed integer programming model has been proposed for waste electrical and electronic goods. In the model (economic, environmental, and social) situations are taken into account. The proposed model is solved by the epsilon constraint method [7]. Temiz, H. (2018), within the scope of disaster logistics, the problem of location selection of logistics warehouses are discussed to deliver emergency supplies to predetermined points of need as soon as possible. In the study, the problem was examined in two stages. In the first stage, the cluster cover model determines the minimum number of locations. In the second stage, it is modeled as a p-median problem for demand-weighted distance minimization [8]. Kececi et al. (2017), in the study, first of all, WEEE amounts for the Çankaya district were estimated by considering user behaviors for television, refrigerator, washing machine, oven, and vacuum cleaner. As a result of the calculations, location selection for the determination of WEEE collection points was considered and solved as a cluster-covering problem [9]. Güray et al. (2016) investigated the amount of electrical and electronic goods used in homes, e-waste production status, and how people manage e-waste in Bursa. A survey study was conducted with 100 people (31 families) with different income levels. As a result of the survey, it has been determined that the use of lamps (fluorescent and other) is higher than other products. It was observed that the highest rate in terms of devices belonged to the mobile phone. When mobile phones become e-waste, it has been observed that 60% are not thrown away and are kept at home [10]. Mehmet et al. (2015) explained the importance of the evaluation of electrical and electronic waste. The economic and environmental effects of recycling these wastes have been studied [11]. Tuncay (2015), in his study, compared the situations related to electrical and electronic wastes in Turkey and the world. He gave information about the recycling of these wastes. He addressed the issue of establishing and optimizing the aggregation structure [12].

Besim (2011) determined various national and international regulations as a solution to the growing problem of electronic waste in the world. Within the scope of this study, various suggestions are given in terms of the damages, management, and control of e-waste [14]. Çiftlik et al. (2009), the legislation of electronic waste was examined in terms of regulation. He made various suggestions for the management, economy, and recovery of these wastes due to the precious metals in them [15]. Esra (2006) examined the studies on the recycling method of electrical and electronic waste in our country. With the pilot project carried out in Muğla province, separate collection and recycling of e-waste from houses and technical services was carried out and the results were stated. As a result, the applicability of the e-waste management approach in the project to the whole country was mentioned [16].

When looking at the literature, survey studies were usually conducted to determine the amount of electronic waste. The e-waste problem has been addressed as economic, social, and societal health and recommendations have been made. This situation has led to the need to create a collection center in the most appropriate location with the idea that the collection infrastructure deficiency of electrical and electronic waste may increase. The low number of e-waste collection centers in Turkey and the lack of collection boxes in places where people can easily reach is a big problem. Studies on p-median in Turkey are less common compared to foreign countries. The studies have generally been handled as recovering the precious metals in electronic wastes to the economy, surveying to measure the electrical and electronic waste awareness level of the society, and recycling processes of electronic waste. Efforts to establish suitable collection places and recycling centers for electrical and electronic waste are scarcely any. No p-median study has been carried out on these wastes. In the study, the p-median problem was addressed when determining the optimal location selection of the warehouse and waste boxes related to e-waste. In this respect, it is thought that the demand-weighted distance and costs will be taken into account and contribute to the literature and environment.

CHAPTER 4

RESEARCH METHODOLOGY

To make appropriate e-waste management in our country, first of all, the amount of e-waste should be known [10]. The amount of waste of electrical and electronic goods may vary from year to year. There are very few studies on the determination of the amount of e-waste produced. When the literature is examined, a survey study was generally conducted to determine the amount of electronic waste. Studies on p-median are less common in Turkey than in foreign countries. The data, updated annually by the Turkish Statistical Institute and the Ministry of Environment and Urbanization, is an open source to be used in studies in many fields. Proper statistics on e-waste figures are not kept in Turkey. The statistics kept are outdated. For this reason, although it is predicted that 500 thousand tons of e-waste are produced on average every year; data, Global e-waste monitoring report, TUIK, Ministry of Environment and Urbanization, Environment and provincial status reports, Exitcom data, data of authorized institutions (Elday, Tubisad, Agid) assigned by the Ministry of Environment and Urbanization were taken into consideration. The data accepted as the most recent year were addressed. This study, in the case, when the provinces are certain with developed electronic waste management applications in various regions of Turkey, focuses on determining the optimal warehouse locations in the districts close to the organized industrial zones covering certain provinces. Since it is difficult for society to leave their wastes from their homes to the places where warehouses are foreseen, it is also planned to create waste collection boxes in central places so that all provinces will receive service.

4.1 Warehouse Location Selection Problem Definition

Warehouse location selection problems have become a more important issue compared to the past. Determination of warehouse locations is also referred to as location selection and assignment models. It is based on the assignment of demand points to specified locations. When the studies conducted in the past years are examined, more than one approach has been developed to solve the p-median problem. Since the p-median problem, which was first introduced by Hakimi in 1964, is an important problem type encountered in real life, it has attracted a lot of attention since it was first introduced and has been studied by many researchers. In short, the warehouse location selection problem is one of the optimization problems encountered quite often in real life. The main problem is to choose the most suitable warehouse location among n-points in a network to reduce the total transportation distance and to assign the demand points to them so that they receive service from the closest warehouse. As such, it can be stated that the problem is a derivative of the p-median facility location problem, which is widely discussed in the literature [25].

4.2 P-median Problem

When it is predicted that there are n-points on the structure called the network, the problem of determining p from these n-points as the facility location and assigning the remaining demand points to the closest facility to them from the facilities determined to receive service represents a p-median problem. The p-median problem is the most well known facility location and assignment model among facility location selection problems and many studies have been made in the literature for its solution (Alp et al., 2003). The p-median problem falls under the category of minisum (minimum sum) facility layout problems. Minisum problems were first formulated by Kuehn and Hamburger (1963), Hakimi (1964), Manne (1964) and Balinski (1965). Hakimi made the first detailed formulation of the p-median problem in 1964. What is meant by minimizing the total average weighted distance is to minimize the total distance between the facility and the demand points, taking into account the demand quantities (Hakimi, 1964; Church and Revelle, 1976).

The p-median problem considered from this point of view focuses on reducing the total delivery time. Cost elements commonly used in the p-median problem can be money, time, and distance. The p-median problem is not only a facility location selection problem but also a model that includes the assignment of demand points that will receive service from the placed facilities to the nearest facility. The model aims to determine the most suitable places for p piece facilities to be opened in a way that will minimize the demand-weighted total distance.

The assumptions of the p-median problem are as follows (Jamshidi, 2009);

1. There is a linear relationship between cost and distance.
2. The number of facilities to be opened is known.
3. There is no time limit.
4. There is no capacity limit for the facilities providing service.
5. There is no cost to open a facility.
6. There is constant customer demand.
7. All facilities are of equal features.
8. The problem structure is discrete (only facilities can be opened on nodes).
9. The points where the facilities can be opened are determined.

The mathematical formulation of the p-median problem was first made by ReVelle and Swain (ReVelle and Swain, 1970). The notation in the formulation is largely the same as the original, although some minor changes have been made over time [30].

4.3 Purpose of the Study

It is known that very little of the e-waste created in our country end up in municipal waste warehouse locations and the vast majority of it is collected informally. Therefore, the registered collection rate is low. The main reason for the low collection rates is the unregistered and uncontrolled collection of e-waste [19]. In this study, our aim is to establish a warehouse location for e-waste that is not collected duly and is emerging inconsistently. A modeling study will be conducted to determine where we should establish this ideal warehouse location and to ensure that demand points receive service from the closest warehouse. And it will be analyzed and the solution stage will be reached.

The fuel consumption cost and the cost of opening a warehouse due to the transportation of the collected electronic wastes to the warehouse locations that are planned to be opened have been calculated. Distance, fuel consumption cost, and warehouse installation cost were evaluated with a mathematical model, and appropriate warehouse location suggestions were made. There are 28 demand points in the study. It is aimed to determine the best warehouse location and number by minimizing the distance between the provinces that will receive service and the places where warehouses can be established, reducing the cost of fuel consumption arising from transportation and the cost of establishing warehouses.

Compared to the warehouse locations opened as a result of optimization, it is difficult for society to leave their wastes from their homes to the places where warehouses are planned to be established. For this reason, it is planned to create waste collection boxes in central places by minimizing the distance traveled by the waste left by individuals depending on the amount of the population, so that all provinces will receive service.

4.4 Mathematical Expression of the Problem

The main problem is to choose the most suitable warehouse location among n piece points in a network in order to reduce the total transportation distance and the fuel consumption cost arising from transportation, the cost of establishing the warehouse. In addition, it is to assign demand points to receive service from the nearest warehouse.

Mathematical models can help to find the most suitable warehouse locations.

a. Indices:

i = Set of demand points (provinces to receive service) (i = 1, 2, ...,m)

j = Selected places in the provinces where candidate warehouses can be established (j=1, 2, ...,n)

b. Parameters:

a_i = amount of WEEE collected in province i (tons)

d_{ij} = distance between the provinces where i will receive service and the places where j warehouses can be established (km)

p = number of warehouses to be placed to serve

c = Fuel consumption unit cost per km ($)

f_j = setup cost of j warehouse($)

c. Variables:

X_{ij} = {1 if the collected e-waste amounts in province i are assigned to warehouse j,

0 in other case

Y_j = {1 if a warehouse is opened in province j,

0 in other case

d. Objective function:

$$Min \sum_{i=1}^{n} \sum_{j=1}^{n} a_i \,.\, c \,.\, d_{ij} . X_{ij} + \sum_{j=1}^{n} f_{j.}\, Y_j \qquad (1.1)$$

Constraints:

$$\sum_{i=1}^{n} X_{ij} = 1 \qquad \forall i, j = 1,2 \ldots., n \qquad (1.2)$$

$$X_{ij} \leq Y_j \qquad \forall i, j = 1,2 \ldots, n \qquad (1.3)$$

$$\sum_{j=1}^{n} Y_{j=P} \qquad (1.4)$$

$$X_{ij}, Y_j \in \{0,1\} \qquad \forall i, j = 1,2 \ldots., n \qquad (1.5)$$

In the study, when the transportation distance between the objective function expressed in equation (1) and the demand-weighted warehouses is minimized, the fuel consumption cost arising from transportation in the objective function expressed in the other factor is minimized. In other words, there is a linear relationship between these two objective functions. The other factor minimizes the cost of establishing a warehouse. Equation (2) ensures that each demand node is assigned to only one warehouse. Equation (3) ensures that demand nodes are assigned only to the open warehouse. Equation (4) determines the number of warehouses planned to be opened.

4.5 Application

Provinces in Turkey where the population is more than 500,000 and the amount of e-waste per capita is high depending on the population have been selected. For this reason, 7 regions in Turkey and 4 provinces from each region were discussed. It is assumed that the places where the warehouse will be established have equal capacity. In the mathematical model of the p-median problem, the number of provinces that will receive services is considered as m = 28 and the number of places where warehouses can be established is considered as n = 28. In other words, there is 28 demand points that will receive service where the study is carried out. It is planned to open a warehouse to increase service quality by reducing the delivery times for these demand points. The concentrations and numbers of collected electronic wastes and e-waste processing facilities have been determined.

- Mediterranean Region: Adana, Mersin, Hatay, Antalya
- Aegean Region: Izmir, Manisa, Denizli, Mugla
- Marmara Region: Istanbul, Kocaeli, Bursa, Sakarya
- Southeastern Anatolia Region: Gaziantep, Diyarbakir, S.Urfa, Mardin
- Central Anatolia Region: Ankara, Konya, Kayseri, Eskisehir
- Black Sea Region: Trabzon, Samsun, Ordu, Zonguldak
- Eastern Anatolia Region: Van, Erzurum, Malatya, Elazig

In Figure 4.1, the provinces where the study was carried out are shown in different colors. There are 28 demand points (provinces) in total.

Figure 4.1 Demand Points (Selected Provinces)

In Figure 4.2, a representation of the selected places on the map was made on Google Earth.

Figure 4.2 Places where candidate warehouses can be established

The places where warehouses are foreseen to be established in figure 4.2 are the districts close to the organized industrial zone in the provinces that will receive service. Electronic waste is classified as hazardous waste. For this reason, to establish a warehouse, it should be in a location away from buildings and human traffic.

The annual data included in the Turkey MEU Environment provincial status reports were found as a result of the research. However, statistical analysis was not performed because sufficient and consistent data on electronic waste collected in provinces Diyarbakir, Trabzon, Ordu, and Van could not be reached. Therefore, these numbers are discussed as 0. However, this does not mean that there is no e-waste in those provinces. For this reason, the population density in these provinces has been taken into account in calculating the amount of e-waste. In addition, there are no facilities for the processing of e-waste in some of our industrially developed and densely populated provinces. For this reason, our aim of the study is to establish a warehouse (collection center) for e-waste that is not collected properly, to ensure that the data is recorded consistently and to be able to deliver it to the appropriate processing facilities easily. The data calculated in the data set below are the data for 2019. Modeling work will be done in line with these data.

Table 4.1 Amount of electronic waste collected in provinces [26].

Provinces	Amount of E- waste collected (tons)
Adana	749634
Mersin	643
Hatay	756
Antalya	31500
Izmir	2,948,920
Manisa	1992
Denizli	387
Mugla	180
Istanbul	3,682,000
Kocaeli	1328
Bursa	578
Sakarya	30
Gaziantep	13071
Diyarbakir	116
Ş.urfa	450
Mardin	21525
Ankara	2,283,000
Konya	106
Kayseri	431
Eskisehir	2386
Trabzon	174
Samsun	70
Ordu	127
Zonguldak	478
Van	53
Erzurum	234
Malatya	11
Elazıg	23

The distance (km) between the places selected for the ideal warehouse was calculated from Google Maps. Distances (km) are given in the table below.

Table 4.2 Distance Between Selected Locations for Ideal Warehouse (km)

COUNTIES	AdanaSaricam	AnkaraYenimahalle	AntalyaDosemealti	BursaNilufer	DenizliHonaz	DiyarbakirYenisehir	ElazigYazikonak	ErzurumAziziye	EskisehirOdunpazari	GaziantepSehitkamil	HatayPayas	MersinAkdeniz	IstanbulTuzla	IstanbulTuzla	KayseriMelikgazi	KocaeliGebze	KonyaSelcuklu	MalatyaYesilyurt	ManisaYunusemre	MardinArtuklu	MuglaMentese	OrduKarapinar	SakaryaArifiye	SamsunTekkekoy	TrabzonArsin	UrfaEyyubiye	VanTusba	ZonguldakCaycuma
AdanaSaricam	0	547	596	901	820	536	450	767	740	168	69	120	955	968	310	942	413	348	940	504	910	699	855	739	852	313	859	792
AnkaraYenimahalle	547	0	486	399	489	849	754	885	237	655	610	487	401	599	322	389	265	653	571	992	626	562	302	426	758	800	1217	239
AntalyaDosemealti	596	486	0	540	241	1143	1049	1247	429	757	658	464	672	462	614	660	320	947	434	1094	314	1046	578	911	1243	902	1448	699
BursaNilufer	901	399	540	0	439	1225	1131	1251	162	1031	964	840	204	326	698	192	500	1029	283	1368	532	898	169	763	1095	1176	1594	390
DenizliHonaz	820	489	241	439	0	1245	1150	1349	364	982	883	706	608	247	716	595	419	1048	220	1319	160	1051	513	915	1247	1127	1613	702
DiyarbakirYenisehir	536	849	1143	1225	1245	0	98	325	1063	368	539	650	1248	1392	529	1235	838	207	1364	151	1381	686	1148	793	597	217	422	1086
ElazigYazikonak	450	754	1049	1131	1150	98	0	321	969	338	453	564	1154	1298	435	1141	743	113	1270	248	1286	601	1054	678	511	314	466	991
ErzurumAziziye	767	885	1247	1251	1349	325	321	0	1122	655	770	881	1187	1484	644	1174	942	431	1456	415	1485	410	1087	546	279	492	409	1008
EskisehirOdunpazari	740	237	429	162	364	1063	969	1122	0	869	803	679	278	425	536	265	338	867	397	1206	501	798	184	663	995	1014	1432	404
GaziantepSehitkamil	168	655	757	1031	982	368	338	655	869	0	171	282	1054	1130	335	1042	575	236	1102	336	1072	685	955	721	838	145	691	892
HatayPayas	69	610	658	964	883	539	453	770	803	171	0	183	1018	1031	414	1005	476	351	1003	507	973	764	918	800	917	316	862	855
MersinAkdeniz	120	487	464	840	706	650	564	881	679	282	183	0	894	907	329	882	353	462	880	618	779	776	795	757	929	427	972	732
IstanbulTuzla	955	401	672	204	608	1248	1154	1187	278	1054	1018	894	0	524	721	13	632	1052	481	1391	744	834	105	698	1031	1199	1588	326
IzmirCigli	968	599	462	326	247	1392	1298	1484	425	1130	1031	907	524	0	863	512	567	1196	45	1466	235	1160	503	1024	1357	1275	1761	723
KayseriMelikgazi	310	322	614	698	716	529	435	644	536	335	414	329	721	863	0	709	309	333	835	672	852	483	621	467	636	480	898	559
KocaeliGebze	942	389	660	192	595	1235	1141	1174	265	1042	1005	882	13	512	709	0	619	1039	468	1378	731	821	92	686	1018	1186	1576	313
KonyaSelcuklu	413	265	320	500	419	838	743	942	338	575	476	353	632	567	309	619	0	641	539	912	555	741	538	605	937	720	1206	510
MalatyaYesilyurt	348	653	947	1029	1048	207	113	431	867	236	351	462	1052	1196	333	1039	641	0	1168	358	1184	560	952	597	621	261	576	889
ManisaYunusemre	940	571	434	283	220	1364	1270	1456	397	1102	1003	880	481	45	835	468	539	1168	0	1439	251	1132	459	997	1329	1247	1733	680
MardinArtuklu	504	992	1094	1368	1319	151	248	415	1206	336	507	618	1391	1466	672	1378	912	358	1439	0	1408	815	1291	943	684	192	441	1228
MuglaMentese	910	626	314	532	160	1381	1286	1485	501	1072	973	779	744	235	852	731	555	1184	251	1408	0	1187	649	1051	1383	1217	1749	838
OrduKarapinar	699	562	1046	898	1051	686	601	410	798	685	764	776	834	1160	483	821	741	560	1132	815	1187	0	734	136	197	811	812	633
SakaryaArifiye	855	302	578	169	513	1148	1054	1087	184	955	918	795	105	503	621	92	538	952	459	1291	649	734	0	599	931	1099	1489	226
SamsunTekkekoy	739	426	911	763	915	793	678	546	663	721	800	757	698	1024	467	686	605	597	997	943	1051	136	599	0	332	847	947	497
TrabzonArsin	852	758	1243	1095	1247	597	511	279	995	838	917	929	1031	1357	636	1018	937	621	1329	684	1383	197	931	332	0	761	680	829
UrfaEyyubiye	313	800	902	1176	1127	217	314	492	1014	145	316	427	1199	1275	480	1186	720	261	1247	192	1217	811	1099	847	761	0	539	1037
VanTusba	859	1217	1448	1594	1613	422	466	409	1432	691	862	972	1588	1761	898	1576	1206	576	1733	441	1749	812	1489	947	680	539	0	1409
ZonguldakCaycuma	792	239	699	390	702	1086	991	1008	404	892	855	732	326	723	559	313	510	889	680	1228	838	633	226	497	829	1037	1409	0

4.6 Fuel Consumption Cost

The fuel consumption calculation is based on the distance traveled or the fuel consumption per km. Fuel consumption varies according to the vehicle engine, fuel, usage style, and place of use. For this reason, fuel consumption is considered as a personal calculation. Generally, the liter consumption per 100 km is shown as standard in the vehicles. Diesel engines have been developed for cases such as carrying loads and traveling long distances, and gasoline engines have been developed for fast acceleration and speed. Diesel-engined vehicles lose less value than gasoline-powered vehicles. Diesel engines are much more efficient engines. Therefore, they release much more energy by consuming less fuel.

When calculating; The amount of fuel consumed by trucks when loaded is usually between 24-30 liters per 100 kilometers. In the study, this value was considered as an average of 27 liters. Let's assume that the fuel consumption of 100 km is shown as 27 liters and the vehicle is diesel. Currently, on 30.03.2022, in a situation where the average price of 1 liter of diesel is \$1.51, it gives us the amount of fuel the vehicle has spent per 100 km as $27 \times 1.51\$ = 40.77\$$. When we divide this amount by 100, 0.4077 \$ finds the unit cost per km of the vehicle.

4.7 Warehouse Setup Cost

The costs spent on warehouse construction are warehouse costs. Electronic waste is classified as hazardous waste. For this reason, to establish a warehouse, it should be in a location away from buildings and human traffic. Depending on the waste type and capacity in the waste regulation, the closed area of the warehouse cannot be less than 1000 m². For this reason, the land area was taken as 4500 m² to establish a warehouse taking advantage of the previous studies. The approximate unit cost of the structure used in the engineering account is $\$153{,}628/\mathrm{m}^2$ for the warehouse in 2022. When calculating the building cost of the provinces, the unit cost of the building and the land area were multiplied. While choosing the land area, it was envisaged to choose a suitable place between the organized industrial zone and the scrap dealers' site for the land cost calculation. The average approximate value was taken at sahibinden.com, as the price of 4500 m² varies from plot to land on a provincial basis, and the land cost was found by multiplying it by the land area.

Building Cost: $153{,}628\$ \times 4500\mathrm{m}^2 = 691326\,\$/\mathrm{m}^2$

Table 4.3 Warehouse Setup Cost (fj)

Candidate Warehouse Locations	**Building Cost ($)**	**Land Cost ($)**	**Total Cost (Cj)**	**Land m² Price($/m²)**
AdanaSaricam	691326	231363.26	922689.26	51,41405727
MersinAkdeniz	691326	138264.9	829590.9	30,72553223
HatayPayas	691326	343204.2	1034530.20	76,2675989
AntalyaDosemealti	691326	768138.31	1459464.31	170,6974013
IzmirCigli	691326	178515.34	869841.34	39,67007606
ManisaYunusemre	691326	498675.39	1190001.39	110,8167529
DenizliHonaz	691326	397588.39	1088914.39	88,35297491
MuglaMentese	691326	249798.58	941124.58	55,5107949
IstanbulTuzla	691326	388370.73	1079696.73	86,3046061
KocaeliGebze	691326	237508.36	928834.36	52,77963648
BursaNilufer	691326	177900.83	869226.83	39,53351814
SakaryaArifiye	691326	602834.94	1294160.94	133,9633205
GaziantepSehitkamil	691326	675961.71	1367287.71	150,2137131

DiyarbakirYenisehir	691326	1676077.78	2367403.78	372,4617296
UrfaEyyubiye	691326	70054.21	761380.21	15,567603
MardinArtuklu	691326	159772.77	851098.77	35,50505947
AnkaraYenimahalle	691326	320160.05	1011486.05	71,14667686
KonyaSelcuklu	691326	95863.66	787189.66	21,30303568
KayseriMelikgazi	6913265	29803.77	721129.77	6,623059171
EskisehirOdunpazari	691326	43323.00	734649.00	9,627333433
TrabzonArsin	691326	33490.83	724816.83	7,442406697
SamsunTekkekoy	691326	368706.39	1060032.39	81,93475263
OrduKarapinar	691326	491608.52	1182934.52	109,2463368
ZonguldakCaycuma	691326	258094.47	949420.47	57,35432684
VanTusba	691326	19049.83	710375.83	4,233295552
ErzurumAziziye	691326	184353.19	875679.19	40,96737631
MalatyaYesilyurt	691326	92176.60	783502.60	20,48368816
ElazigYazikonak	691326	30725.53	722051.53	6,827896052

As can be seen from the table, most of the places chosen to establish warehouses are suitable places between the organized industrial zone and the scrap dealers' site. For each province, the places where the industrial and scrap dealers' sites are concentrated were taken into account on google maps. However, since the industry is not very developed in some provinces when searching for places close to the industrial zone from google maps, it usually shows the places in the center of the provinces. For this reason, while sahibinden.com is determining the location of the land on a provincial basis, the land area that is more suitable for establishing a warehouse has been considered and the locations have been specified in this way.

4.8 Using Cplex for the Solution of the Model

In the solution phase of the p-median problem model, the most optimal result is achieved by solving it with the IBM ILOG CPLEX computer program. As an assumption, the maximum number of warehouses that can be opened is 28. Scenarios for P=1-2-3-4…28 are examined. And for each number p, the optimal warehouse location, the demand points (provinces) that can receive services and the total distance traveled(km), the fuel consumption cost spent per km ($) and the cost of opening a warehouse ($) were taken into account in the model.

The IBM ILOG CPLEX program is a program that is often used in operations research on mathematical model solving. In CPLEX, the model is developed using the opl language. This model is saved in a mod file. In addition, the mod file can be used for the data or the model can be run by creating a separate data file. IBM ILOG CPLEX is frequently used in the literature on mathematical models. Files with mod and data extensions are required for CPLEX to work. Various tools and programs are used for the optimization of warehouse placement problems. It is one of some programs used in CPLEX [28].

After the model is solved, 0-1 in the tables shows the output for binary variables. As a result of the optimal solution, the value of the objective function gives the number of warehouses to be opened on whichever table is smaller. Because the total distance and cost minimization were taken into consideration in the problem. The places where the result is '1' indicate the optimal warehouse location to be opened and the provinces that will receive (assign) service.

CHAPTER 5

RESULTS

In this section, the location-allocation model, called p-median problems for 28 different scenarios, is applied;

Scenario 1: The situation in which 1 existing warehouse is being addressed

The optimal location for 1 warehouse opened is Kocaeli Gebze. The optimal solution is the value 1339334450 for the objective function. The solution speed of the problem is 4.321 seconds.

Scenario 2: The situation in which 2 existing warehouse is being addressed

The optimal locations for the 2 warehouses opened are Izmir Cigli and Istanbul Tuzla. The optimal solution is the value 745145446 for the objective function. The solution speed of the problem is 4.243 seconds.

Scenario 3: The situation in which 3 existing warehouse is being addressed

The optimal locations for the 3 warehouses opened are Ankara Yenimahalle, Izmir Cigli, and Istanbul Tuzla. The optimal solution is the value 269424217 for the objective function. The solution speed of the problem is 4.024 seconds.

Scenario 4: The situation in which 4 existing warehouse is being addressed

The optimal locations for the 4 warehouses opened are Adana Saricam, Ankara Yenimahalle, Istanbul Tuzla, and Izmir Cigli. The optimal solution is the value 121660893 for the objective function. The solution speed of the problem is 4.040 seconds.

Scenario 5: The situation in which 5 existing warehouse is being addressed

The optimal locations for the 5 warehouses opened are Adana Saricam, Ankara Yenimahalle, Istanbul Tuzla, Izmir Cigli, and Konya Selcuklu. The optimal solution is the value 120811971 for the objective function. The solution speed of the problem is 4.102 seconds.

Scenario 6: The situation in which 6 existing warehouse is being addressed

The optimal locations for the 6 warehouses opened are Adana Saricam, Ankara Yenimahalle, Istanbul Tuzla, Izmir Cigli, Konya Selcuklu, and Mardin Artuklu. The optimal solution is the value 139541940 for the objective function. The solution speed of the problem is 4.446 seconds.

Scenario 7: The situation in which 7 existing warehouse is being addressed

The optimal locations for the 7 warehouses opened are Adana Saricam, Ankara Yenimahalle, Istanbul Tuzla, Izmir Cigli, Konya Selcuklu, Mardin Artuklu, and Van Tusba. The optimal solution is the value 159422399 for the objective function. The solution speed of the problem is 4.134 seconds.

Scenario 8: The situation in which 8 existing warehouse is being addressed

The optimal locations for the 8 warehouses opened are Adana Saricam, Ankara Yenimahalle, Eskisehir Odunpazari, Istanbul Tuzla, Izmir Cigli, Konya Selcuklu, Mardin Artuklu, and Van Tusba. The optimal solution is the value 179554138 for the objective function. The solution speed of the problem is 4.165 seconds.

Scenario 9: The situation in which 9 existing warehouse is being addressed

The optimal locations for the 9 warehouses opened are Adana Saricam, Ankara Yenimahalle, Eskisehir Odunpazari, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Konya Selcuklu, Mardin Artuklu, and Van Tusba. The optimal solution is the value 199795577 for the objective function. The solution speed of the problem is 4.321 seconds.

Scenario 10: The situation in which 10 existing warehouse is being addressed

The optimal locations for the 10 warehouses opened are Adana Saricam, Ankara Yenimahalle, Elazig Yazikonak, Eskisehir Odunpazari, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Konya Selcuklu, Mardin Artuklu, and Van Tusba. The optimal solution is the value 220125304 for the objective function. The solution speed of the problem is 4.134 seconds.

Scenario 11: The situation in which 11 existing warehouse is being addressed

The optimal locations for the 11 warehouses opened are Adana Saricam, Ankara Yenimahalle, Elazig Yazikonak, Eskisehir Odunpazari, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Konya Selcuklu, Mardin Artuklu, Trabzon Arsin, and Van Tusba. The optimal solution is the value 240772510 for the objective function. The solution speed of the problem is 4.274 seconds.

Scenario 12: The situation in which 12 existing warehouse is being addressed

The optimal locations for the 12 warehouses opened are Adana Saricam, Ankara Yenimahalle, Elazig Yazikonak, Eskisehir Odunpazari, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Konya Selcuklu, Mardin Artuklu, Trabzon Arsin, Urfa Eyyubiye, and Van Tusba. The optimal solution is the value 262710087 for the objective function. The solution speed of the problem is 4.087 seconds.

Scenario 13: The situation in which 13 existing warehouse is being addressed

The optimal locations for the 13 warehouses opened are Adana Saricam, Ankara Yenimahalle, Elazig Yazikonak, Eskisehir Odunpazari, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Konya Selcuklu, Malatya Yesilyurt, Mardin Artuklu, Trabzon Arsin, Urfa Eyyubiye, and Van Tusba. The optimal solution is the value 284855917 for the objective function. The solution speed of the problem is 4.134 seconds.

Scenario 14: The situation in which 14 existing warehouse is being addressed

The optimal locations for the 14 warehouses opened are Adana Saricam, Ankara Yenimahalle, Elazig Yazikonak, Eskisehir Odunpazari, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Konya Selcuklu, Malatya Yesilyurt, Mardin Artuklu, Trabzon Arsin, Urfa Eyyubiye, and Van Tusba. The optimal solution is value 308053007 for the objective function. The solution speed of the problem is 4.087 seconds.

Scenario 15: The situation in which 15 existing warehouse is being addressed

The optimal locations for the 15 warehouses opened are Adana Saricam, Ankara Yenimahalle, Bursa Nilufer, Elazig Yazikonak, Eskisehir Odunpazari, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Konya Selcuklu, Malatya Yesilyurt, Mardin Artuklu, Trabzon Arsin, Urfa Eyyubiye, and Van Tusba. The optimal solution is the value 332353187 for the objective function. The solution speed of the problem is 4.227 seconds.

Scenario 16: The situation in which 16 existing warehouse is being addressed

The optimal locations for the 16 warehouses opened are Adana Saricam, Ankara Yenimahalle, Bursa Nilufer, Elazig Yazikonak, Erzurum Aziziye, Eskisehir Odunpazari, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Konya Selcuklu, Malatya Yesilyurt, Mardin Artuklu, Trabzon Arsin, Urfa Eyyubiye, and Van Tusba. The optimal solution is the value 356845582 for the objective function. The solution speed of the problem is 4.180 seconds.

Scenario 17: The situation in which 17 existing warehouse is being addressed

The optimal locations for the 17 warehouses opened are Adana Saricam, Ankara Yenimahalle, Bursa Nilufer, Elazig Yazikonak, Erzurum Aziziye, Eskisehir Odunpazari, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Kocaeli Gebze, Konya Selcuklu, Malatya Yesilyurt, Mardin Artuklu, Trabzon Arsin, Urfa Eyyubiye, and Van Tusba. The optimal solution is the value 382845737 for the objective function. The solution speed of the problem is 4.212 seconds.

Scenario 18: The situation in which 18 existing warehouse is being addressed

The optimal locations for the 18 warehouses opened are Adana Saricam, Ankara Yenimahalle, Bursa Nilufer, Elazig Yazikonak, Erzurum Aziziye, Eskisehir Odunpazari, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Kocaeli Gebze, Konya Selcuklu, Malatya Yesilyurt, Mardin Artuklu, Mugla Mentese, Trabzon Arsin, Urfa Eyyubiye, and Van Tusba. The optimal solution is the value 409089209 for the objective function. The solution speed of the problem is 4.461 seconds.

Scenario 19: The situation in which 19 existing warehouse is being addressed

The optimal locations for the 19 warehouses opened are Adana Saricam, Ankara Yenimahalle, Bursa Nilufer, Elazig Yazikonak, Erzurum Aziziye, Eskisehir Odunpazari, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Kocaeli Gebze, Konya Selcuklu, Malatya Yesilyurt, Mardin Artuklu, Mugla Mentese, Trabzon Arsin, Urfa Eyyubiye, Van Tusba, and Zonguldak Caycuma. The optimal solution is the value 435626393 for the objective function. The solution speed of the problem is 4.103 seconds.

Scenario 20: The situation in which 20 existing warehouse is being addressed

The optimal locations for the 20 warehouses opened are Adana Saricam, Ankara Yenimahalle, Bursa Nilufer, Denizli Honaz, Elazig Yazikonak, Erzurum Aziziye, Eskisehir Odunpazari, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Kocaeli Gebze, Konya Selcuklu, Malatya Yesilyurt, Mardin Artuklu, Mugla Mentese, Trabzon Arsin, Urfa Eyyubiye, Van Tusba, and Zonguldak Caycuma. The optimal solution is the value 464571966 for the objective function. The solution speed of the problem is 4.196 seconds.

Scenario 21: The situation in which 21 existing warehouse is being addressed

The optimal locations for the 21 warehouses opened are Adana Saricam, Ankara Yenimahalle, Bursa Nilufer, Denizli Honaz, Elazig Yazikonak, Erzurum Aziziye, Eskisehir Odunpazari, Hatay Payas, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Kocaeli Gebze, Konya Selcuklu, Malatya Yesilyurt, Mardin Artuklu, Mugla Mentese, Trabzon Arsin, Urfa Eyyubiye, Van Tusba, and Zonguldak Caycuma. The optimal solution is the value 494098807 for the objective function. The solution speed of the problem is 4.025 seconds.

Scenario 22: The situation in which 22 existing warehouse is being addressed

The optimal locations for the 22 warehouses opened are Adana Saricam, Ankara Yenimahalle, Bursa Nilufer, Denizli Honaz, Elazig Yazikonak, Erzurum Aziziye, Eskisehir Odunpazari, Hatay Payas, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Kocaeli Gebze, Konya Selcuklu, Malatya Yesilyurt, Mardin Artuklu, Mugla Mentese, Samsun Tekkekoy, Trabzon Arsin, Urfa Eyyubiye, Van Tusba, and Zonguldak Caycuma. The optimal solution is the value 523765900 for the objective function. The solution speed of the problem is 4.415 seconds.

Scenario 23: The situation in which 23 existing warehouse is being addressed

The optimal locations for the 23 warehouses opened are Adana Saricam, Ankara Yenimahalle, Bursa Nilufer, Denizli Honaz, Elazig Yazikonak, Erzurum Aziziye, Eskisehir Odunpazari, Hatay Payas, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Kocaeli Gebze, Konya Selcuklu, Malatya Yesilyurt, Mardin Artuklu, Mugla Mentese, Ordu Karapinar, Samsun Tekkekoy, Trabzon Arsin, Urfa Eyyubiye, Van Tusba, and Zonguldak Caycuma. The optimal solution is the value 556878433 for the objective function. The solution speed of the problem is 3.884 seconds.

Scenario 24: The situation in which 24 existing warehouse is being addressed

The optimal locations for the 24 warehouses opened are Adana Saricam, Ankara Yenimahalle, Bursa Nilufer, Denizli Honaz, Elazig Yazikonak, Erzurum Aziziye, Eskisehir Odunpazari, Hatay Payas, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Kocaeli Gebze, Konya Selcuklu, Malatya Yesilyurt, Manisa Yunusemre, Mardin Artuklu, Mugla Mentese, Ordu Karapinar, Samsun Tekkekoy, Trabzon Arsin, Urfa Eyyubiye, Van Tusba, and Zonguldak Caycuma. The optimal solution is the value 590161914 for the objective function. The solution speed of the problem is 4.477 seconds.

Scenario 25: The situation in which 25 existing warehouse is being addressed

The optimal locations for the 25 warehouses opened are Adana Saricam, Ankara Yenimahalle, Antalya Dosemealti, Bursa Nilufer, Denizli Honaz, Elazig Yazikonak, Erzurum Aziziye, Eskisehir Odunpazari, Hatay Payas, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Kocaeli Gebze, Konya Selcuklu, Malatya Yesilyurt, Manisa Yunusemre, Mardin Artuklu, Mugla Mentese, Ordu Karapinar, Samsun Tekkekoy, Trabzon Arsin, Urfa Eyyubiye, Van Tusba, and Zonguldak Caycuma. The optimal solution is the value 626397297 for the objective function. The solution speed of the problem is 4.290 seconds.

Scenario 26: The situation in which 26 existing warehouse is being addressed

The optimal locations for the 26 warehouses opened are Adana Saricam, Ankara Yenimahalle, Antalya Dosemealti, Bursa Nilufer, Denizli Honaz, Elazig Yazikonak, Erzurum Aziziye, Eskisehir Odunpazari, Hatay Payas, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Kocaeli Gebze, Konya Selcuklu, Malatya Yesilyurt, Manisa Yunusemre, Mardin Artuklu, Mugla Mentese, Ordu Karapinar, Sakarya Arifiye, Samsun Tekkekoy, Trabzon Arsin, Urfa Eyyubiye, Van Tusba, and Zonguldak Caycuma. The optimal solution is the value 663908649 for the objective function. The solution speed of the problem is 4.259 seconds.

Scenario 27: The situation in which 27 existing warehouse is being addressed

The optimal locations for the 27 warehouses opened are Adana Saricam, Ankara Yenimahalle, Antalya Dosemealti, Bursa Nilufer, Denizli Honaz, Elazig Yazikonak, Erzurum Aziziye, Eskisehir Odunpazari, Gaziantep Sehitkamil, Hatay Payas, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Kocaeli Gebze, Konya Selcuklu, Malatya Yesilyurt, Manisa Yunusemre, Mardin Artuklu, Mugla Mentese, Ordu Karapinar, Sakarya Arifiye, Samsun Tekkekoy, Trabzon Arsin, Urfa Eyyubiye, Van Tusba, and Zonguldak Caycuma. The optimal solution is the value 701678587 for the objective function. The solution speed of the problem is 4.102 seconds.

Scenario 28: The situation in which 28 existing warehouse is being addressed

The optimal locations for the 28 warehouses opened are Adana Saricam, Ankara Yenimahalle, Antalya Dosemealti, Bursa Nilufer, Denizli Honaz, Diyarbakir Yenisehir, Elazig Yazikonak, Erzurum Aziziye, Eskisehir Odunpazari, Gaziantep Sehitkamil, Hatay Payas, Mersin Akdeniz, Istanbul Tuzla, Izmir Cigli, Kayseri Melikgazi, Kocaeli Gebze, Konya Selcuklu, Malatya Yesilyurt, Manisa Yunusemre, Mardin Artuklu, Mugla Mentese, Ordu Karapinar, Sakarya Arifiye, Samsun Tekkekoy, Trabzon Arsin, Urfa Eyyubiye, Van Tusba, and Zonguldak Caycuma. The optimal solution is the value 767961264 for the objective function. The solution speed of the problem is 4.196 seconds.

The planned warehouse locations and numbers have been considered as 28 different scenarios. The table below shows the comparison of 28 different scenarios.

Table 5.1 Comparison of p=1,2,3,4,...28

Number of Warehouses	Solution (optimal) with objective	Solving CPU Elapsed Time in (Seconds)
P=1	1339334450	4.321
P=2	745145446	4.243
P=3	269424217	4.024
P=4	121660893	4.040
P=5	120811971	4.180
P=6	139541940	4.446
P=7	159422399	4.134
P=8	179554138	4.165
P=9	199795577	4.321
P=10	220125304	4.134
P=11	240772510	4.274
P=12	262710087	4.087
P=13	284855917	4.134
P=14	308053007	4.087
P=15	332353187	4.227
P=16	356845582	4.180
P=17	382845737	4.212
P=18	409089209	4.461
P=19	435626393	4.103
P=20	464571966	4.196
P=21	494098807	4.025
P=22	523765900	4.415
P=23	556878433	3.884
P=24	590161914	4.477
P=25	626397297	4.290
P=26	663908649	4.259
P=27	701678587	4.102
P=28	767961264	4.196

In the case of P=1, all demand nodes are assigned to a warehouse. For cases, P>1, demand nodes are assigned to the nearest warehouse.

To determine the optimum number of warehouses, the number of warehouses-optimal goal solution graph was drawn in line with the total distance traveled and the total cost.

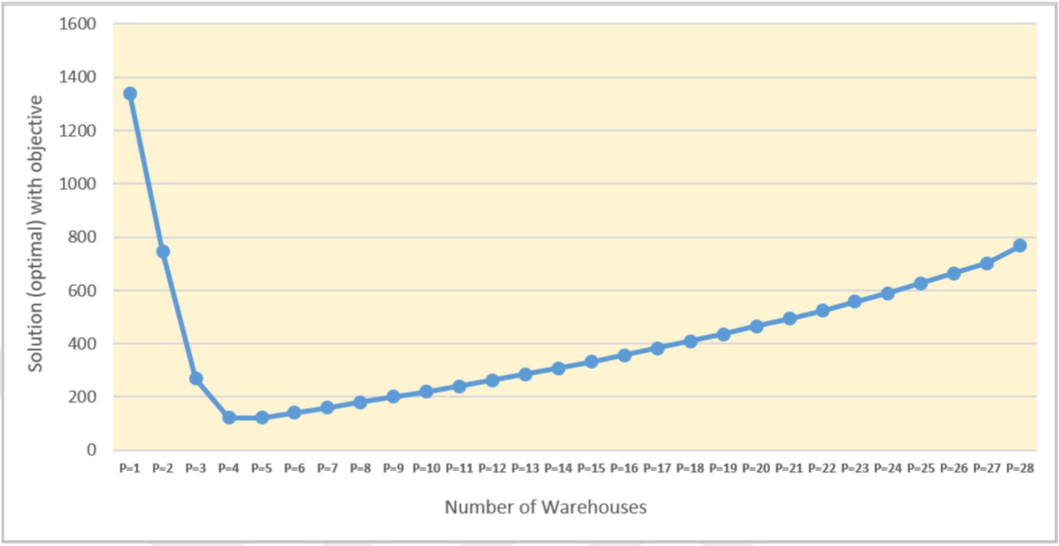

Figure 5.1 Number of Warehouses - Optimal Purpose Solution

As the number of warehouses to be opened increases, the distance decreases. Since the fuel consumption cost has a linear relationship with the distance traveled, the fuel consumption cost decreases as the number of warehouses increases. However, when the cost of opening a warehouse is taken into account, the result changes. As the number of warehouses increases, the cost of opening a warehouse increases. Our aim of this study is to ensure that all demand points receive services from the nearest warehouse with demand weighted distance minimization taking into account the cost. For this reason, as a result of optimization, it has been determined that the minimum number of solution warehouses is 5.

The optimal number of warehouses is p=5 in the minimization problem. The optimal objective function is 120811971 and the places where the warehouse will be established are Adana Saricam, Ankara Yenimahalle, Istanbul Tuzla, Izmir Cigli, and Konya Selcuklu. Figure 5.2 shows the places where warehouses are to be established.

Figure 5.2 Places Where It is Foreseen to Establish Warehouse

In the places where a warehouse is planned to be established, the provinces that will receive services from the warehouse closest to them are as follows.

- AdanaSaricam: Adana, Diyarbakir, Elazig, Erzurum, Gaziantep, Hatay, Mersin, Malatya, Mardin, Urfa, Van
- AnkaraYenimahalle: Ankara, Eskisehir, Ordu, Samsun, Trabzon, Zonguldak
- IstanbulTuzla: Bursa, Istanbul, Kocaeli, Sakarya
- IzmirCigli: Denizli, Izmir, Manisa, Mugla
- KonyaSelcuklu: Antalya, Kayseri, Konya

Table 5.2 Optimal Number of 5 Warehouses

// solution (optimal) with objective 120811971

// Quality Incumbent solution:

// MILP objective 1,2081197125e+08

// MILP solution norm |x| (Total, Max) 3,20000e+01 1,00000e+00

// MILP solution error (Ax=b) (Total, Max) 0,00000e+00 0,00000e+00

// MILP x bound error (Total, Max) 0,00000e+00 0,00000e+00

// MILP x integrality error (Total, Max) 0,00000e+00 0,00000e+00

// MILP slack bound error (Total, Max) 0,00000e+00 0,00000e+00

//

Assign = [[**1**

0 0 0 0 **1 1 1** 0 **1 1 1** 0 0 0 0 0 **1** 0 **1** 0 0 0 0 0 **1 1** 0]

[0 **1** 0 0 0 0 0 0 **1** 0 0 0 0 0 0 0 0 0 0 0 0 0 **1** 0 **1 1** 0 0 **1**]

[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]

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[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]];

Open = [**1 1** 0 0 0 0 0 0 0 0 0 0 **1 1** 0 0 **1** 0 0 0 0 0 0 0 0 0 0 0];

Solving CPU Elapsed Time in (Seconds): 4.180

5.1 Distribution of Processing Facilities and Warehouses

Looking at the distribution of licensed e-waste processing facilities by province in Turkey, it is seen that the majority of the facilities are concentrated in cities such as Ankara, Istanbul, Kocaeli, Bursa, and Eskisehir. The number of facilities where electronic wastes are processed has been received from the environmental provincial status reports published by the Ministry of Environment and Urbanization. As can be seen in the figure, warehouses have been established as a result of optimization in places close to the provinces where processing facilities are concentrated.

Figure 5.3 Distribution of Processing Facilities and Warehouses

5.2 To Be Created Problem Definition and Mathematical Modeling of the Waste Collection Box Compared To the Opened Warehouse Places

Compared to the warehouses opened, it is difficult for society to leave their wastes from their homes to the places where warehouses are planned to be established. For this reason, it is planned to create waste collection boxes in central places so that all provinces will receive service. While the least amount of waste can occur from a province with a large population, it is possible to occur much more waste from a province with a low population. Therefore, the number of individuals per km^2 multiplied by the amount of waste was entered into the model as a demand parameter. It is aimed to determine the most suitable places for the creation of waste collection boxes by minimizing the distance traveled by individuals depending on the population.

a. Indices

i= i. Candidate Collection Box Locations in Cities
j= j. Opened Warehouse Locations

b. Parameters:

d_{ij}= i with candidate collection box in cities j distance between opened warehouse locations (km)
w_i= Population amount in province i
a_i= Amount of waste in province i (tons)

c. Variables:

X_{ij} = {1 if the waste coming to the collection box in province i is assigned to the warehouse j,

0 in other case

Y_i= {1 if province i has a collection box,

0 in other case

d. Objective Function:

$$Min \sum_{i=1}^{n} \sum_{j=1}^{n} a_i . w_i . d_{ij} . X_{ij} \qquad (1.1)$$

Constraints:

$$\sum_{i=1}^{n} Y_i \leq P_{max} \qquad (1.2)$$

$$\sum_{i=1}^{n} X_{ij} \geq 1 \qquad \forall i, j = 1,2 \ldots., n \qquad (1.3)$$

$$\sum_{i=1}^{n} Y_i \geq 1 \qquad \forall i, j = 1,2 \ldots., n \qquad (1.4)$$

$$X_{ij} \leq Y_i \qquad \forall i, j = 1,2 \ldots., n \qquad (1.5)$$

$$X_{ij}, Y_i \in \{0,1\} \qquad \forall i, j = 1,2 \ldots., n \qquad (1.6)$$

In the study, the objective function expressed in Equation (1) is to determine the most appropriate location of the waste collection boxes by minimizing the distance traveled by the waste left by the individuals depending on the population amount. Yi refers to the creation or non-creation of waste collection boxes. The maximum number of collection boxes to be opened, the Pmax =28 constraint is also given in Equation (2). Equation (3) is the constraint that more than one waste collection box can receive services from a warehouse. Equation (4) is the constraint of creating at least one waste collection box. Equation (5) every waste collection box must receive service from the opened warehouse places. In Equation (6), 0.1 is the condition of being an integer.

Table 5.3 Distance Between the Candidate Waste Collection Box Locations to Receive Services and the Opened Warehouse Locations (km)

	AdanaSaricam	AnkaraYenimahalle	IstanbulTuzla	IzmirCigli	KonyaSelcuklu
Adana	11	490	897	910	356
Ankara	503	7	407	639	260
Antalya	559	476	655	471	288
Bursa	868	386	152	362	495
Denizli	773	497	568	285	411
Diyarbakir	529	906	1305	1450	895
Elazig	487	797	1113	1289	747
Erzurum	800	897	1186	1510	937
Eskisehir	701	234	263	519	319
Gaziantep	215	662	1102	1133	574
Hatay	188	681	1081	1112	558
Mersin	79	486	894	907	353
Istanbul	961	427	47	496	680
Izmir	918	520	528	32	546
Kayseri	291	366	740	888	304
Kocaeli	851	346	56	479	570
Konya	368	286	661	579	19
Malatya	388	709	1084	1231	658
Manisa	897	570	387	64	528
Mardin	540	1035	1410	1471	910
Mugla	868	597	639	240	555
Ordu	697	585	852	1184	740
Sakarya	813	294	107	525	532
Samsun	726	424	691	1023	585
Trabzon	829	820	1051	1381	860
Urfa	346	869	1244	1275	716
Van	896	1269	1644	1809	1207
Zonguldak	775	240	298	830	535

5.3 Opened Warehouse Locations Compared to Scenario Results of Created Waste Collection Box

The location-allocation model, called p-median problems, is applied for different scenarios.

If Assign[c][w] <= Open[c];

Waste collection boxes are formed in each province. Waste collection box formed in Sakarya province receives service from Istanbul Tuzla warehouse.

Table 5.4 Optimal Solution

// solution (optimal) with objective 3305176500
// Quality Incumbent solution:
// MILP objective 3,3051765000e+09
// MILP solution norm |x| (Total, Max) 2,90000e+01 1,00000e+00
// MILP solution error (Ax=b) (Total, Max) 0,00000e+00 0,00000e+00
// MILP x bound error (Total, Max) 0,00000e+00 0,00000e+00
// MILP x integrality error (Total, Max) 0,00000e+00 0,00000e+00
// MILP slack bound error (Total, Max) 0,00000e+00 0,00000e+00
//

Assign = [[0
0 0 0 0]
[0 0 0 0 0]
[0 0 0 0 0]
[0 0 0 0 0]
[0 0 0 0 0]
[0 0 0 0 0]
[0 0 0 0 0]
[0 0 0 0 0]
[0 0 0 0 0]
[0 0 0 0 0]
[0 0 0 0 0]
[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 **1** 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]];

Open = [**1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1**];

Solving CPU Elapsed Time in (Seconds): 4.1808268

The comparison of the optimal solution results of the waste collection boxes planned to be created and the CPU elapsed times of the problem are shown in the table below.

If Assign[c][w] = = Open[c];

Table 5.5 Comparison of p=1,2,3,4,...28

Number of Waste Collection Boxes	Solution (optimal) with objective	Solving CPU Elapsed Time in (Seconds)
P=1	0	4.1496266
P=2	0	4.2432272
P=3	0	4.4772287
P=4	0	4.3212277
P=5	35,823,387,050	4.368028
P=6	96,091,148,032	4.9296316
P=7	166,241,202,532	4.4304284
P=8	491,819,697,592	4.1964269
P=9	944,496,032,564	4.4772287
P=10	1,457,519,191,004	4.3056276
P=11	2,220,517,099,456	4.3992282
P=12	3,170,976,067,096	4.2432272
P=13	4,188,122,389,960	4.3836281
P=14	5,758,592,389,291	4.056026
P=15	8,976,238,704,016	4.1028263
P=16	12,973,686,449,696	4.1496266
P=17	17,126,098,484,696	4.3992282
P=18	21,437,359,737,296	4.5396291
P=19	25,895,186,524,976	4.3056276
P=20	31,865,723,889,936	4.3212277
P=21	38,885,003,025,888	4.4148283
P=22	135,766,504,176,588	4.1964269
P=23	235,467,853,303,572	4.3992282
P=24	429,229,182,253,572	4.3836281
P=25	489,845,125,704,301	4.3836281
P=26	2,827,765,433,957,100	4.3056276
P=27	6,104,100,053,490,350	4.2900275
P=28	21,023,860,873,133,700	4.5084289

Supposing we have created at least one waste collection box in each province in the model, there is one waste collection box in each of the 28 provinces. Assuming that more than one waste collection box can receive services from a warehouse and each waste collection box should receive service from the opened warehouse locations, the waste collection boxes formed in all provinces receive service from the opened warehouse locations. The optimum solution is a great value of 21,023,860,873,133,700.

At least one waste collection box should be formed in each province. A maximum of one waste collection box can receive services from a warehouse, and assuming that each waste collection box should receive service from the opened warehouse locations, there is only one waste collection box in Adana province. The created waste collection box can receive service from the opened warehouse location (Adana Saricam) can receive service. The solution does not give an optimal result.

Since we aim for minimization in the problem, it gives the most appropriate result when the number of waste collection boxes is p=5. Waste collection boxes are formed in Diyarbakır, Malatya, Ordu, Trabzon, and Van provinces. The waste collection boxes formed can receive service from the opened warehouse locations (Adana Saricam, Ankara Yenimahalle, Istanbul Tuzla, Izmir Cigli, and Konya Selcuklu). When there are 5 waste boxes, the optimal solution is 35823387050. CPU solution time of the problem is 4.368028 seconds.

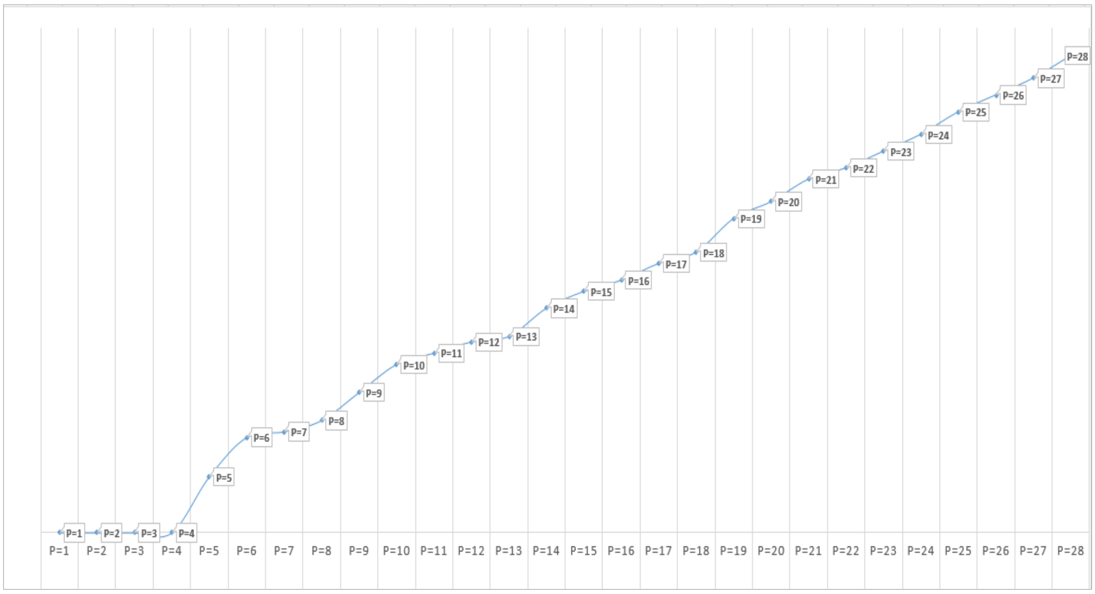

Figure 5.4 Waste Collection Box Optimal Solution

The optimal solution graph of the waste collection boxes created compared to the opened warehouse locations was drawn. The problem has binary variable programming. Since we have 5 warehouses in total, P=1-2-3-4 does not give an optimal solution when we create a waste box. Since we aim to minimize the distance traveled by the wastes left by the individuals in the problem depending on the population amount, it gives the most appropriate result when the number of waste collection boxes is 5.

Table 5.6 Optimal Number of 5 Waste Collection Boxes

```
// solution (optimal) with objective 35823387050
// Quality Incumbent solution:
// MILP objective                                  3,5823387050e+10
// MILP solution norm |x| (Total, Max)             3,00000e+01  1,00000e+00
// MILP solution error (Ax=b) (Total, Max)         0,00000e+00  0,00000e+00
// MILP x bound error (Total, Max)                 0,00000e+00  0,00000e+00
// MILP x integrality error (Total, Max)           0,00000e+00  0,00000e+00
// MILP slack bound error (Total, Max)             0,00000e+00  0,00000e+00
//
```

Assign = [[0

0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[1 1 1 1 1]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[1 1 1 1 1]

[0 0 0 0 0]

[0 0 0 0 0]

[0 0 0 0 0]

[1 1 1 1 1]

[0 0 0 0 0]

[0 0 0 0 0]

[1 1 1 1 1]

[0 0 0 0 0]

[1 1 1 1 1]

[0 0 0 0 0]];

Open = [0 0 0 0 0 **1** 0 0 0 0 0 0 0 0 0 0 0 0 **1** 0 0 0 **1** 0 0 **1** 0 **1** 0];

Solving CPU Elapsed Time in (Seconds): 4.36802

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Today, the amount of electronic waste in Turkey continues to increase gradually. As a result of this study, a detailed literature study was made by examining the e-waste management practices applied in our country and internationally. The current situation and emerging problems in Turkey are discussed. The information and data obtained were carried out through one-on-one interviews with experts in institutions. These institutions; Face-to-face, telephone, and e-mail interviews were held with the personnel working at the Ministry of Environment and Urbanization, Adana Provincial Directorate of Environment and Urbanization, Tuik, Tubisad, Elday, Agid, and Exitcom. Within the scope of the study, the most optimal warehouse location was determined to establish a waste collection center (warehouse) for electronic wastes that are not collected properly in Turkey. The p-median warehouse location problem is discussed. The IBM OPL CPLEX program was used to determine the number and location of warehouses to be opened. In the solution phase of this problem, the optimal warehouse location and number were determined by analyzing it through computer software. It was decided that the optimal number of warehouses was 5. As a result of the optimization, it was decided to open warehouses in Adana Saricam, Ankara Yenimahalle, Istanbul Tuzla, Izmir Cigli, and Konya Selcuklu. Compared to the warehouses opened, it is difficult for society to leave their wastes from their homes to the places where warehouses are planned to be established. It is planned to create waste collection boxes in central places so that all provinces will receive service. The most suitable places for the creation of waste collection boxes were determined by minimizing the distance traveled by the wastes left by the individuals depending on the population amount.

As a result of the optimization, when the number of waste collection boxes is 5, it gives the most appropriate result. Waste collection boxes are formed in Diyarbakır, Malatya, Ordu, Trabzon, and Van provinces. The waste collection boxes formed can receive services from the opened warehouse locations (Adana Saricam, Ankara Yenimahalle, Istanbul Tuzla, Izmir Cigli, and Konya Selcuklu).

As a society, we have responsibilities to do to reduce electronic waste. First of all, we need to think in detail before buying a new electrical and electronic product. If we need this product, the lease option should be preferred before purchasing. We should not let electronic goods become waste to keep up with the rapidly developing technology. The best way to reduce electronic product waste most effectively is to use them for as long as possible. If some electronic items are out of use, we can donate these products to EVFT and support the education of many children while benefiting the environment. While donating, it is possible to take the electronic waste to the nearest PTO branch and send the waste to the Recycling Factory free of charge.

The amount of e-waste collected by authorized institutions and the category they belong to must be continuously processed into the system. In this way, the amount of waste created in each province becomes clearer numerically. The number of waste collection boxes should be increased in the separate collection of electronic waste. Collection centers should be built in places that are easily accessible to the public. Places that are easily accessible to the public are important for recycling. Society, which is a producer of electronic waste, should know that it harms the environment and the economy in the process that they do not recycle this waste. All segments of society should be reached of the damage caused in the process when e-waste is not handled correctly should be explained. In this way, it can be shown that e-waste is a type of recyclable waste.

As future work, it is important to solve it based on current data. It has been understood that with the widely used p-median method, a solution to the problem of choosing a warehouse location for electronic waste on a regional basis can be produced in Turkey. It is thought that it can be addressed in future studies. A study with a larger data set should be carried out to locate appropriate electronic waste collection boxes in every neighborhood and every street in Turkey.

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APPENDIX A

MODEL TESTING

Mod File

```
// P-Median

main{
        // Generating & Solving initial model
        thisOplModel.generate(); // Generating the current model instance
                if (cplex.solve())
                {
                var ofile = new
IloOplOutputFile("C:/Users/merve/opl/PMedian/Answer.txt");
                ofile.writeln(thisOplModel.printSolution());
                ofile.writeln("Solving CPU Elapsed Time  in (Seconds): ",
cplex.getCplexTime());
                ofile.close();
                var obj = cplex.getObjValue();
                writeln("The Value of the Objective Function Value is (Total Weighted
Distance): ", obj);
                writeln("Solving CPU Elapsed Time  in (Seconds): ",
cplex.getCplexTime());
                thisOplModel.postProcess();
                }
        else {
                        writeln("No Solution");
                 }
```

```
// indicies

{string} Provinces =...;
{string} Warehouses =...;

// Parameters and Data

// amount of WEEE collected in province
 float Demand[Provinces] =...;
 float Distance[Provinces][Warehouses]=...;
// number of warehouses to serve
int MaxWarehousesP =...;
float FuelConsumptionCost =...;
float WarehouseSetupCost[Provinces]=...;


// Decision Variables

// 1 if the collected e-waste amounts in province i are assigned to warehouse j 0 in other cases
dvar boolean Assign[Provinces][Warehouses];
dvar boolean Open[Warehouses];

// Model

// minimize distance, fuel consumption cost and warehouse setup cost
// Total demand weighted distance
minimize sum(p in Provinces, w in Warehouses) Assign[p][w] *
(FuelConsumptionCost * Distance[p][w]*Demand[w]) + sum(p in Provinces, w in
Warehouses) WarehouseSetupCost[p]*Open[p];
```

```
subject to{

 forall (w in Warehouses)
   //1 if province and warehouse match
   EachProvincesDemandMustBeMet:
         sum( p in Provinces ) Assign[p][w]==1;
//check if warehouse open or not
   forall (p in Provinces, w in Warehouses)
   CannotAssignProvincestoWH_UnlessItIsOpen:
     Assign[p][w] <= Open[p];
   UseMaximum_P_Warehouses:
         sum(p in Provinces) Open[p]==MaxWarehousesP;
}
```

Dat File

```
Provinces=
{AdanaSaricam,AnkaraYenimahalle,AntalyaDosemealti,BursaNilufer,DenizliHonaz,DiyarbakirYenisehir,ElazigYazikonak,ErzurumAziziye,EskisehirOdunpazari,GaziantepSehitkamil,HatayPayas,MersinAkdeniz,IstanbulTuzla,IzmirCigli,KayseriMelikgazi,KocaeliGebze,KonyaSelcuklu,MalatyaYesilyurt,ManisaYunusemre,MardinArtuklu,MuglaMentese,OrduKarapinar,SakaryaArifiye,SamsunTekkekoy,TrabzonArsin,UrfaEyyubiye,VanTusba,ZonguldakCaycuma};

Warehouses =
{AdanaSaricam,AnkaraYenimahalle,AntalyaDosemealti,BursaNilufer,DenizliHonaz,DiyarbakirYenisehir,ElazigYazikonak,ErzurumAziziye,EskisehirOdunpazari,GaziantepSehitkamil,HatayPayas,MersinAkdeniz,IstanbulTuzla,IzmirCigli,KayseriMelikgazi,KocaeliGebze,KonyaSelcuklu,MalatyaYesilyurt,ManisaYunusemre,MardinArtuklu,MuglaMentese,OrduKarapinar,SakaryaArifiye,SamsunTekkekoy,TrabzonArsin,UrfaEyyubiye,VanTusba,ZonguldakCaycuma};
```

Demand= [749634, 2283000, 31500, 578, 387, 116, 23, 234, 2386, 13071, 756, 643, 3682000, 2948920, 431, 1328, 106, 11, 1992, 21525, 180, 174, 30, 70, 127, 450, 53, 478];

Distance =

[[0 ,547 ,596 ,901 ,820 ,536 ,450 ,767 ,740 ,168 ,69 ,120
,955 ,968 ,310 ,942 ,413 ,348 ,940 ,504 ,910 ,699 ,855
,739 ,852 ,313 ,859 ,792]

[547 ,0 ,486 ,399 ,489 ,849 ,754 ,885 ,237 ,655 ,610 ,487
,401 ,599 ,322 ,389 ,265 ,653 ,571 ,992 ,626 ,562 ,302
,426 ,758 ,800 ,1217 ,239]

[596 486 ,0 ,540 ,241 ,1143 ,1049 ,1247 ,429 ,757 ,658 ,464
,672 ,462 ,614 ,660 ,320 ,947 ,434 ,1094 ,314 ,1046 ,578
,911 ,1243 ,902 ,1448 ,699]

[901 399 ,540 ,0 ,439 ,1225 ,1131 ,1251 ,162 ,1031 ,964 ,840
,204 ,326 ,698 ,192 ,500 ,1029 ,283 ,1368 ,532 ,898 ,169
,763 ,1095 ,1176 ,1594 ,390]

[820 ,489 ,241 ,439 ,0 ,1245 ,1150 ,1349 ,364 ,982 ,883 ,706
,608 ,247 ,716 ,595 ,419 ,1048 ,220 ,1319 ,160 ,1051 ,513
,915 ,1247 ,1127 ,1613 ,702]

[536 ,849 ,1143 ,1225 ,1245 ,0 ,98 ,325 ,1063 ,368 ,539 ,650
,1248 ,1392 ,529 ,1235 ,838 ,207 ,1364 ,151 ,1381 ,686
,1148 ,793 ,597 ,217 ,422 ,1086]

[450 ,754 ,1049 ,1131 ,1150 ,98 ,0 ,321 ,969 ,338 ,453 ,564
,1154 ,1298 ,435 ,1141 ,743 ,113 ,1270 ,248 ,1286 ,601
,1054 ,678 ,511 ,314 ,466 ,991]

[767 ,885 ,1247 ,1251 ,1349 ,325 ,321 ,0 ,1122 ,655 ,770 ,881
,1187 ,1484 ,644 ,1174 ,942 ,431 ,1456 ,415 ,1485 ,410
,1087 ,546 ,279 ,492 ,409 ,1008]

[740 ,237 ,429 ,162 ,364 ,1063 ,969 ,1122 ,0 ,869 ,803 ,679
,278 ,425 ,536 ,265 ,338 ,867 ,397 ,1206 ,501 ,798 ,184
,663 ,995 ,1014 ,1432 ,404]

[168 ,655 ,757 ,1031 ,982 ,368 ,338 ,655 ,869 ,0 ,171 ,282
,1054 ,1130 ,335 ,1042 ,575 ,236 ,1102 ,336 ,1072 ,685 ,955
,721 ,838 ,145 ,691 ,892]
[69 ,610 ,658 ,964 ,883 ,539 ,453 ,770 ,803 ,171 ,0 ,183
,1018 ,1031 ,414 ,1005 ,476 ,351 ,1003 ,507 ,973 ,764 ,918
,800 ,917 ,316 ,862 ,855]
[120 ,487 ,464 ,840 ,706 ,650 ,564 ,881 ,679 ,282 ,183 ,0
,894 ,907 ,329 ,882 ,353 ,462 ,880 ,618 ,779 ,776 ,795
,757 ,929 ,427 ,972 ,732]
[955 ,401 ,672 ,204 ,608 ,1248 ,1154 ,1187 ,278 ,1054 ,1018 ,894
,0 ,524 ,721 ,13 ,632 ,1052 ,481 ,1391 ,744 ,834 ,105
,698 ,1031 ,1199 ,1588 ,326]
[968 ,599 ,462 ,326 ,247 ,1392 ,1298 ,1484 ,425 ,1130 ,1031 ,907
,524 ,0 ,863 ,512 ,567 ,1196 ,45 ,1466 ,235 ,1160 ,503
,1024 ,1357 ,1275 ,1761 ,723]
[310 ,322 ,614 ,698 ,716 ,529 ,435 ,644 ,536 ,335 ,414 ,329
,721 ,863 ,0 ,709 ,309 ,333 ,835 ,672 ,852 ,483 ,621
,467 ,636 ,480 ,898 ,559]
[942 ,389 ,660 ,192 ,595 ,1235 ,1141 ,1174 ,265 ,1042 ,1005 ,882
,13 ,512 ,709 ,0 ,619 ,1039 ,468 ,1378 ,731 ,821 ,92
,686 ,1018 ,1186 ,1576 ,313]
[413 ,265 ,320 ,500 ,419 ,838 ,743 ,942 ,338 ,575 ,476 ,353
,632 ,567 ,309 ,619 ,0 ,641 ,539 ,912 ,555 ,741 ,538
,605 ,937 ,720 ,1206 ,510]
[348 ,653 ,947 ,1029 ,1048 ,207 ,113 ,431 ,867 ,236 ,351 ,462
,1052 ,1196 ,333 ,1039 ,641 ,0 ,1168 ,358 ,1184 ,560 ,952
,597 ,621 ,261 ,576 ,889]
[940 ,571 ,434 ,283 ,220 ,1364 ,1270 ,1456 ,397 ,1102 ,1003 ,880
,481 ,45 ,835 ,468 ,539 ,1168 ,0 ,1439 ,251 ,1132 ,459
,997 ,1329 ,1247 ,1733 ,680]
[504 ,992 ,1094 ,1368 ,1319 ,151 ,248 ,415 ,1206 ,336 ,507 ,618
,1391 ,1466 ,672 ,1378 ,912 ,358 ,1439 ,0 ,1408 ,815
,1291 ,943 ,684 ,192 ,441 ,1228]

[910 ,626 ,314 ,532 ,160 ,1381 ,1286 ,1485 ,501 ,1072 ,973 ,779
,744 ,235 ,852 ,731 ,555 ,1184 ,251 ,1408 ,0 ,1187 ,649
,1051 ,1383 ,1217 ,1749 ,838]
[699 ,562 ,1046 ,898 ,1051 ,686 ,601 ,410 ,798 ,685 ,764 ,776
,834 ,1160 ,483 ,821 ,741 ,560 ,1132 ,815 ,1187 ,0 ,734
,136 ,197 ,811 ,812 ,633]
[855 ,302 ,578 ,169 ,513 ,1148 ,1054 ,1087 ,184 ,955 ,918 ,795
,105 ,503 ,621 ,92 ,538 ,952 ,459 ,1291 ,649 ,734 ,0
,599 ,931 ,1099 ,1489 ,226]
[739 ,426 ,911 ,763 ,915 ,793 ,678 ,546 ,663 ,721 ,800 ,757
,698 ,1024 ,467 ,686 ,605 ,597 ,997 ,943 ,1051 ,136 ,599
,0 ,332 ,847 ,947 ,497]
[852 ,758 ,1243 ,1095 ,1247 ,597 ,511 ,279 ,995 ,838 ,917 ,929
,1031 ,1357 ,636 ,1018 ,937 ,621 ,1329 ,684 ,1383 ,197 ,931
,332 ,0 ,761 ,680 ,829]
[313 ,800 ,902 ,1176 ,1127 ,217 ,314 ,492 ,1014 ,145 ,316 ,427
,1199 ,1275 ,480 ,1186 ,720 ,261 ,1247 ,192 ,1217 ,811
,1099 ,847 ,761 ,0 ,539 ,1037]
[859 ,1217 ,1448 ,1594 ,1613 ,422 ,466 ,409 ,1432 ,691 ,862 ,972
,1588 ,1761 ,898 ,1576 ,1206 ,576 ,1733 ,441 ,1749 ,812
,1489 ,947 ,680 ,539 ,0 ,1409]
[792 ,239 ,699 ,390 ,702 ,1086 ,991 ,1008 ,404 ,892 ,855 ,732
,326 ,723 ,559 ,313 ,510 ,889 ,680 ,1228 ,838 ,633 ,226
,497 ,829 ,1037 ,1409 ,0]];

MaxWarehousesP = 28;

FuelConsumptionCost= 0.4077;

WarehouseSetupCost=
[922689,1011486,1459464,869227,1088914,2367404,722052,875679,734649,1367288,1034530, 829591, 1079697, 869841, 721130, 928834, 95864, 783503, 1190001, 851099, 941125, 1182935, 1294161, 1060032, 724817, 761380, 710376, 949420];

Mod File

```
// P-Median Waste Collection Boxes

main{
	// Generating & Solving initial model
	thisOplModel.generate(); // Generating the current model instance
		if (cplex.solve())
		{
		var ofile = new
IloOplOutputFile("C:/Users/merve/opl/PMedian/Answer.txt");
		ofile.writeln(thisOplModel.printSolution());
		ofile.writeln("Solving CPU Elapsed Time  in (Seconds): ",
cplex.getCplexTime());
		ofile.close();
		var obj = cplex.getObjValue();
		writeln("The Value of the Objective Function Value is (Total Weighted
Distance): ", obj);
		writeln("Solving CPU Elapsed Time  in (Seconds): ",
cplex.getCplexTime());
		thisOplModel.postProcess();
		}
	else {
			writeln("No Solution");
		 }

	}

// indicies

{string} CollectionBoxes =...;
{string} Warehouses =...;
```

```
// Parameters and Data

// amount of WEEE collected in province
 float PopulationAmount [CollectionBoxes] =...;
 float WasteAmount [CollectionBoxes] =...;
 float Distance[CollectionBoxes][Warehouses]=...;
// number of collection boxes to serve
int MaxCollectionBoxesP =...;

// Decision Variables

// 1 if the waste coming to the collection box in province i is assigned to the warehouse
j 0 in other cases
dvar boolean Assign[CollectionBoxes][Warehouses];
dvar boolean Open[CollectionBoxes];

// Model

// minimize distance
// Total demand weighted distance
minimize sum(c in CollectionBoxes, w in Warehouses)
Assign[c][w]*Distance[c][w]*PopulationAmount[c]*WasteAmount[c];

subject to{

  forall (w in Warehouses)
    //1 more than one waste collection box can receive service from a warehouse
    EachCollectionBoxesDemandMustBeMet:
      sum(c in CollectionBoxes, w in Warehouses) Assign[c][w]>=1;
//if there is a collection box, there must be at least 1
  forall(c in CollectionBoxes)
   sum(c in CollectionBoxes) Open[c]>=1;
//Each waste collection box should receive service from the opened warehouse
locations
    forall(c in CollectionBoxes,w in Warehouses)
    AssignCollectionBoxestoWH_ItIsOpen:
      Assign[c][w] <= Open[c];
```

```
    UseMaximum_P_CollectionBoxes:
        sum(c in CollectionBoxes) Open[c]==MaxCollectionBoxesP;

}
```

Dat File

```
CollectionBoxes=
{Adana,Ankara,Antalya,Bursa,Denizli,Diyarbakir,Elazig,Erzurum,Eskisehir,Gaziantep,Hatay,Mersin,Istanbul,Izmir,Kayseri,Kocaeli,Konya,Malatya,Manisa,Mardin,Mugla,Ordu,Sakarya,Samsun,Trabzon,Urfa,Van,Zonguldak};

Warehouses =
{AdanaSaricam,AnkaraYenimahalle,IstanbulTuzla,IzmirCigli,KonyaSelcuklu};

PopulationAmount= [2237940, 5639076, 2511700, 3056120, 1037208, 1756353, 591098, 762062, 887475, 2069364, 1628894, 1840425, 15519267, 4367251, 1407409, 1953035, 2232374, 800165, 1440611, 838778, 983142, 754198, 1029650, 1348542, 808974, 2073614, 1136757, 596053];

WasteAmount= [749634, 2283000, 31500, 578, 387, 116, 23, 234, 2386, 13071, 756, 643, 3682000, 2948920, 431, 1328, 106, 11, 1992, 21525, 180, 174, 30, 70, 127, 450, 53, 478];

Distance =
[[11   ,490  ,897  ,910  ,356]
[503   ,7    ,407  ,639  ,260]
[559   ,476  ,655  ,471  ,288]
[868   ,386  ,152  ,362  ,495]
[773   ,497  ,568  ,285  ,411]
[529   ,906  ,1305 ,1450 ,895]
[487   ,797  ,1113 ,1289 ,747]
[800   ,897  ,1186 ,1510 ,937]
[701   ,234  ,263  ,519  ,319]
[215   ,662  ,1102 ,1133 ,574]
```

```
[188   ,681   ,1081  ,1112  ,558]
[79    ,486   ,894   ,907   ,353]
[961   ,427   ,47    ,496   ,680]
[918   ,520   ,528   ,32    ,546]
[291   ,366   ,740   ,888   ,304]
[851   ,346   ,56    ,479   ,570]
[368   ,286   ,661   ,579   ,19]
[388   ,709   ,1084  ,1231  ,658]
[897   ,570   ,387   ,64    ,528]
[540   ,1035  ,1410  ,1471  ,910]
[868   ,597   ,639   ,240   ,555]
[697   ,585   ,852   ,1184  ,740]
[813   ,294   ,107   ,525   ,532]
[726   ,424   ,691   ,1023  ,585]
[829   ,820   ,1051  ,1381  ,860]
[346   ,869   ,1244  ,1275  ,716]
[896   ,1269  ,1644  ,1809  ,1207]
[775   ,240   ,298   ,830   ,535]];
```

MaxCollectionBoxesP = 28;

CURRICULUM VITAE

Name and Surname: Ayşe KÖKYILDIRIM

1.1 Education

	Graduate School	Year
Master:	Gaziantep University Industrial Engineering	2023
Bachelor:	Cyprus International University Industrial Engineering	2019
High School:	Seyhan 24 November Anatolian High School	2015