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Research Article

Electrical and Electronic Waste (E-Waste) Warehouse and Collection Box Location Selection in Turkey

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Abstract

The amount of electronic waste (e-waste) is steadily increasing due to the rapid and unconscious consumption of technological products in Turkey today. This study aims to address the current situation of electrical and electronic goods in Turkey. The registered collection rate of electronic waste (e-waste) in our country is low. The primary reason for these low collection rates is the unregistered and uncontrolled gathering of electronic waste (e-waste). These waste materials need to be reintegrated into the economy. Without a suitable collection infrastructure, it becomes challenging to effectively recover electronic waste. The scarcity of electronic waste (e-waste) collection centers in Turkey and the absence of collection boxes in easily accessible areas constitute a significant issue. As part of this study, the optimal location for establishing waste collection centers (warehouses) for electronic waste improperly collected in Turkey was determined. The IBM OPL CPLEX program was utilized to identify the number and locations of the warehouses to be opened. The study comprises 28 demand points, and the P-median problem was employed as a location-allocation model to ensure the most suitable service for these demand points. As a result of the optimization, the appropriate locations for the warehouses to be opened have been determined. It is challenging for the community to transport their waste from their homes to the locations where warehouses are planned to be established. To ensure that all provinces receive service, there is a plan to install waste collection boxes in central locations.

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

Türkiye'de Elektrikli ve Elektronik Atık (E-Atık) Depo ve Toplama Kutusu Yer Seçimi

Öz

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 elektronik atıkların (e-atık) kayıtlı toplama oranı düşüktür. Toplama oranlarının düşük olmasının ana sebebi kayıtsız ve kontrolsüz şekilde toplanan elektronik atıklardır. Bu atıkların ekonomiye geri kazandırılması gerekmektedir. Uygun bir toplama yapısı olmadan, ortaya çıkan elektronik atıkları geri kazanmak zordur. Türkiye'de elektronik atık (e-atık) toplama merkezlerinin düşük sayıda olması ve insanların kolaylıkla ulaşabileceği yerlerde toplama kutularının olmaması büyük sorundur. Çalışma kapsamında Türkiye'de uygun şekilde toplanmayan elektronik atıklar için atık toplama merkezi (depo) kurulması amacıyla en optimal depo yeri belirlenmiştir. Açılması gereken depo sayısı ve yerini belirlemek için IBM OPL CPLEX programı kullanılmıştır. Çalışmada 28 adet talep noktası vardır. Bu talep noktalarına en uygun hizmetin sağlanabilmesi için P-medyan problemi lokasyon tahsis modeli olarak uygulanmıştır. Optimizasyon sonucunda açılması düşünülen uygun depo yerlerine karar verilmiştir. Toplumun atıklarını evlerinden, depo kurulması öngörülen yerlere bırakması zordur. Tüm iller hizmet alacak şekilde merkezi yerlere de atık toplama kutularının oluşturulması planlanmıştır.

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

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1. Introduction

The concept of electronic waste was first published in Turkey on May 22, 2012, in the Electrical and Electronic Equipment Waste Control Regulation. All electronic equipment that we do not want to use is obsolete or is not in working condition is called 'electronic waste' or '(e-waste)'. Electrical and electronic equipment is in areas of use such as computers, mobile phones, televisions, white equipment, and small household appliances. This equipment turns into waste electrical and electronic equipment at the end of its useful life. Therefore, waste electrical and electronic equipment needs to be managed following the legislation (Salihoglu et al. 2016). Dozens of harmful elements, which are not found in any of the equipment around us, are located in electronic equipment. The environment and human health are among the main reasons for the proper management of electronic waste (Akpulat, 2020).

1.1. Electrical and Electronic Waste Potential 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 (Akpulat, 2020). For these cities to respond to production, waste management must be done well. According to research, the countries that produce the most electronic waste in the world are; "The USA ranks 1st with 7 million tons, China ranks 2nd with 6 million tons, Japan ranks 3rd with 2.2 million tons of waste, and Turkey ranks 17th in the world with 503 thousand tons (Şahin & Taşer 2023). 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 (Akpulat, 2020).

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 electronic 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 waste of electrical and electronic 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 waste electrical and electronic as a big city where consumption is also very intense.

1.1.1. Evaluation of Electrical and Electronic Waste

In society, people buy different electrical and electronic equipment to meet their needs. After using electrical and electronic equipment, if the equipment becomes waste, it should be recycled. To eliminate environmental problems, the recycling stage becomes a necessity. While 1–5 g of gold is produced 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, this waste should be recycled. The amount of electrical and electronic waste foreseen in Turkey varies from year to year. According to the research, between 10.000 and 25.000 tons, i.e., 2.5% of the annual electrical and electronic waste, are recycled (Co-Brand, 2020). It is an important factor that needs to be recovered by the economy due to the valuable substances in electronic equipment waste. If the electronic waste is not to be used, the last step to be taken is to dispose of it and incinerate it. As a result of the incineration of electrical and electronic equipment waste in open places, uncontrolled decomposition, and irregular warehouses, combustion preventers are mixed into the environment. This situation harms human health (Akın & Kuru, 2011).

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 waste. The organizations responsible for the collection, recycling, and recovery of electronic waste are as follows: the Electrical and Electronics Recycling and Waste Management Association (ELDAY), the Lighting Equipment Manufacturers Association (AGID), the Informatics Industry Association (TUBISAD), and the electronic waste recycling firm in Kocaeli, Exitcom Recycling. It recycles computers, mobile phones, tablets, and end-of-life electrical and electronic goods according to European Union (EU) standards. Turk Telekom's “Bring Your Electronic Waste, Leave a Greener World for Tomorrow!” campaign has contributed to recycling by collecting 18 tons of electronic waste in 3 years. Electronic goods users produce electronic waste. Developed countries generate a large portion of electronic waste and are trying to solve the electronic waste problem by exporting it to Asian and African countries (Işık & Macit 2020).

1.1.2. Collection Process of Electrical and Electronic Waste

The responsibility for electronic waste collection falls on the municipality. Three methods are applied by municipalities to collect electronic waste. Collection in waste collection centers, waste accumulation points, and door collection methods. These methods are used mixed by municipalities (Akpulat, 2020). In European countries, municipalities use these three methods together. These methods are not considered alternatives but complementary. The most commonly used and economical method is to bring electronic waste to points determined by municipalities. Electronic waste collected using these methods is sent to processing facilities.

According to electronic waste regulations, the criteria for municipalities to establish collection centers have been determined. According to these criteria, municipalities are obliged to establish a collection center in settlements with a population of 50,000–100,000 in 2016 and settlements with less than 10,000 inhabitants in 2018 (REC, 2016).

Examples of electronic waste collection activities are given below.

Electronic Waste Collection Activities in Turkey: In a study carried out by Kadıköy Municipality in Istanbul province, a waste collection vehicle was purchased and electronic waste collection boxes were placed in various parts of the district. Under the title "Aid Campaign to Anatolia," electronic waste was collected, and reusable electronic items were adapted and sent to various schools in Anatolia. In Kocaeli, an electronic waste collection campaign was launched. Kocaeli Metropolitan Municipality stated that 98 tons of electronic waste were recycled in 5 years. With the "Don't Throw, Donate" project developed by the Turkish Education Volunteers Foundation (TEGV) in cooperation with the Ministry of Environment and Urbanization and the Turkish Informatics Industrialists Association (TUBISAD), more than 50 tons of electronic waste were collected and recycled (Sarıyar et al., 2021).

Electronic Waste Collection Activities in the World: When the studies of countries in Europe are examined, Sweden is among the examples of good practice in collecting electronic waste in partnership with municipalities. In addition, Finland tops the European sample countries in terms of electronic waste collection. A cooperation has been established between municipalities and El-Kretsen (a non-profit service initiative), which is responsible for the collection of electronic waste in Sweden. The Finnish State aimed to collect waste mobile phones and batteries by appropriate methods with the "Mobile Phone Throwing Competition" in 2000. With this competition, increasing awareness about electronic waste has become fun (Sarıyar et al., 2021). In Germany, producers can transfer their responsibilities for the management of electronic waste collection by signing a contract directly with a logistics and collection company.

In the source scan performed, the processing of electronic equipment waste in Turkey is very low compared to the number of electronic equipment that have occurred. The reason for this is the unregistered and uncontrolled collection of electrical and electronic equipment waste. Scrap dealers and some informal businesses collect electronic equipment waste unregistered. And they process these wastes in their way. Therefore, the registered collection rate is low. These processes harm the environment and human health. In addition to the low collection rates, the small number of electronic waste collection centers is also a problem in reaching the collection targets. Without a suitable collection structure, it is difficult to process and recycle the resulting electronic waste (Akpulat, 2020).

It is necessary to establish a suitable storage place for unregistered and uncontrolled collected electronic waste in Turkey. A modeling study was carried out to determine where we should set up this ideal warehouse location and to ensure that demand points receive service from the closest warehouse. It is difficult for society to leave their wastes from their homes to places where warehouses are planned. For this reason, it is planned to create waste collection boxes in central places so that all provinces will receive service. Another model has been considered in the creation of waste collection boxes in the most suitable places compared to the opened warehouse locations. It has been analyzed, and the solution stage has been reached. In the solution phase of the P median problem model, the most optimal result was achieved by solving the IBM ILOG CPLEX computer program.

The other parts of the study are as follows: In the literature review section, previous studies are included. In the second section of the study, a binary variable programming model of the p-median problem was proposed, and applications were mentioned. The third section contains the solution results of the proposed model. In the last section, recommendations are made regarding the results and future studies.

1.2. 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 include applications and examinations, are explained in detail below.

With the increase in technological developments, academic studies have gained momentum. Liu et al. (2023) present a global solution for the recycling of electronic waste in this study. Sahin et al. (2023) discussed the positives and negatives of the reverse logistics process for electronic waste and the issues that should be turned into advantages. Ghulam et al. (2023) made suggestions regarding more effective management of electronic waste for a circular economy and sustainable development. Singh et al. (2022) created a decision-making model. The study aims to decide on the optimum electronic waste collection options in a particular region. Sariyar et al. (2021) conducted a survey study of 100 people in the Bahçelievler neighborhood, which was selected as a pilot region in Samsun. The survey study aims to determine the electrical and electronic equipment consumption behaviors and awareness levels of the people living in the neighborhood. Kara & Yurdakul (2021) developed a solution to the problem of determining the optimum number of stations and station locations of the metro line to be built in the Gebze and Darıca districts with cluster coverage and an alternative service level p-median model. Ahirwar et al. (2021) discussed strategies that can be applied to make the recycling of electronic waste an efficient and safe process. Işık & Macit (2020) A mathematical model has been created to decide which of the 10 selected cities to establish recycling centers for waste from electronic waste collection centers in 38 cities in Turkey. The study 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. Ersen & Sel (2020) used the p-median method to determine the most suitable dealer locations among various provinces of Turkey for the company operating in the automotive sector. It aimed to minimize the distances and the number of carbon emissions. It has been studied that the selection of the best facility location takes into account environmental sensitivity for the company. Ruan et al. (2020) proposed a mathematical model for the location of waste electrical and electronic equipment (WEEE) collection points. The purpose of the study was to minimize transportation costs between demand and collection points. Sentürk (2019) surveyed 100 people randomly in the Sivas Center. It has determined the level of awareness among people about electronic equipment waste. Nguyen et al. (2019) introduce a three-stage electronic waste collection system model. The amount of electronic waste to be collected, the allocation of waste containers, the location of electronic waste processing facilities, and the route of collection vehicles are discussed. He focused on solving the problem of electronic waste collection in many ways. Kaya & Koruca (2018) compared the regulations in our country on electronic waste with the regulations in other countries. He made various suggestions about electrical and electronic waste. Alver et al. (2018) proposed a multi-purpose mixed-integer programming model for waste electrical and electronic equipment. The proposed model is solved by the Epsilon constraint method. Temiz, H. (2018) dealt with the problem of the location selection of logistics warehouses to deliver emergency aid materials to predetermined points of need within the scope of disaster logistics as soon as possible. In the study, the problem was examined in two stages. In the first stage, it is the cluster coverage model that determines the minimum number of locations. In the second stage, it is modeled as a p-median problem for demand-weighted distance minimization. Kececi et al. (2017) first estimated the amount of waste electrical and electronic equipment (WEEE) in the Cankaya district. As a result of the calculations, the site selection of waste electrical and electronic equipment (WEEE) collection points was considered and solved as a cluster-covering problem. Salihoglu et al. (2016) investigated the amount of electrical and electronic equipment used in homes, electronic waste equipment status, and how people manage electronic waste in Bursa. A survey study was conducted with 100 people (31 families) with different income levels. Celik (2015) compared the situations in Turkey and around the world in his study on electrical and electronic waste. Kiddee et al. (2013) evaluated the harmful substances found in electronic waste, the effects of these wastes on the environment and human health, and the management strategies currently used in certain countries. Oliveira et al. (2012) described the electronic waste systems used in different countries in their study. He also compared the situation in the world with the current Brazilian reality. Achillas et al. (2010) within the scope of the management of electrical and electronic equipment, have developed a methodology that aims to position purification and recycling units in the most appropriate way. Ciftlik et al. (2009) made several suggestions for the management, economy, and recovery of electronic waste due to the precious metals in it. Gramatyka et al. (2007) described the current situation regarding the recycling of electrical and electronic equipment waste in Europe. Yılmaz (2006) stated the results by conducting a separate collection and recycling study of electronic waste from houses and technical services in a pilot project in Muğla. In the literature review we conducted during our research, Işık & Macit (2020) and Kececi et al. (2017) can be referenced. In this study, they specified suitable places for minimizing the costs of electronic waste recycling centers and determining electronic waste estimated collection points. However, they did not provide a detailed analysis throughout Turkey.

When looking at the literature, survey studies were usually conducted to determine the amount of electronic waste. The electronic waste problem has been addressed in terms of 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 electronic waste collection centers in Turkey and the lack of collection boxes in places where people can easily reach them are big problems. Studies on p-median in Turkey are less common compared to foreign countries. The studies have generally focused on recovering valuable metals from electronic waste for the economy, surveying to measure society's awareness of electrical and electronic waste, and recycling processes for electronic waste. Efforts to establish suitable collection locations and recycling centers for electrical and electronic waste are scarce. 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 electronic waste. In this respect, it is thought that demand-weighted distance and costs will be taken into account and contribute to the literature and environment.

2. Material and Method

2.1. Warehouse Location Selection Problem

Warehouse location selection problems have become a more important issue compared to the past. The 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 (Durak et al., 2015).

2.2. P-median Problem

The p-median problem is the most well-known facility location and assignment model among facility location selection problems, and there have been many studies on its solution in the literature (Alp et al., 2003). Hakimi made the first detailed formulation of the p-median problem in 1964. The aim of 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).

2.1.1. Mathematical Expression of the Problem

The main problem is choosing the most suitable warehouse location among n points in a network to reduce total transportation distance, fuel consumption costs, and the cost of warehouse establishment. Additionally, it is necessary to assign demand points to receive service from the closest warehouse.

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 (Waste Electrical and Electronic Equipment) 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 electronic 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:

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

Constraints:

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

$$X_{ij} \leq Y_j \qquad \forall i, j = 1,2 \dots., n \qquad (3)$$

$$\sum_{j=1}^{n} Y_j = \mathrm{p} \qquad (4)$$

$$X_{ij}, Y_j \in \{0,1\} \qquad \forall i, j = 1,2 \dots., n \qquad (5)$$

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. In equation (5), 0,1 is the condition of being an integer.

2.2.2. Application

Provinces in Turkey with populations over 500,000 and high levels of electronic waste per capita have been selected. This is why seven regions in Turkey and four provinces from each region were considered. 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, the study will be conducted at 28 demand points. It is planned to open a warehouse to increase service quality by reducing delivery times for these demand points.

- 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 1, the provinces where the study was carried out are shown in different colors. There are a total of 28 demand points (provinces).

Figure 1. Demand Points, Selected Provinces (https://paintmaps.com/tr)

The places where warehouses are foreseen to be established in Figure 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.

Figure 2. Selected Districts (https://earth.google.com)

The annual data included in the Turkey Ministry of Environment and Urbanization (MEU) Environment provincial status reports were discovered during the research. These data will be used for modeling work. It is included in Table 1 below.

Table 1. Amount of electronic waste collected in provinces
(Turkey Ministry of Environment and Urbanization, Provincial Status Reports)

Provinces	**Amount of electronic 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 2 below.

Table 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

2.2.3. Fuel Consumption Unit Cost

Fuel consumption calculation is determined by the distance traveled, or fuel consumption per km. Fuel consumption varies depending on the vehicle's engine, fuel type, method of use, and place of use. Therefore, fuel consumption is considered a personal calculation. Within the scope of the research, liter consumption per 100 km is generally shown as standard in vehicles.

Studies conducted on waste collection and transportation costs in previous years have determined that transporting waste collected by small vehicles to long-distance transfer centers reduces vehicle efficiency. For this reason, waste containers must have large volumes. Informatics Industrialists Association (TUBISAD), İzmit Waste and Residues Treatment, Incineration, and Evaluation (IZAYDAS), and licensed organizations authorized by the Ministry of Environment and Urbanization collect electronic waste with waste transportation trucks. To give an example of the type of waste transportation truck, waste transportation is carried out by Izmit Waste and Residues Treatment, Incineration, and Evaluation (IZAYDAS) with the "Ford Cargo 3242S" vehicle, which has a larger carrying capacity. While collecting waste, the amount of fuel consumed was accepted as 27 liters, based on taking advantage of previous studies. Diesel vehicles consume 27 liters of fuel per 100 km. Currently, on March 30, 2022, when the average price of 1 liter of diesel is \$1.51, this gives us the amount of fuel consumed by the vehicle per 100 km as 27 × \$1.51 = \$40.77. When we divide this amount by 100, \$0.4077 represents the fuel unit cost of the vehicle per km.

2.2.4. 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/m² for the warehouse in 2022 (Official Newspaper, 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 approximate average value was taken at sahibinden.com, as the price of 4500 m² varies from plot to plot on a provincial basis. The cost of land was found by multiplying it by the area of the land.

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

Table 3. Warehouse Setup Cost (f_j)

Candidate Warehouse Locations	Building Cost (\$)	Land Cost (\$)	Total Cost (C_j)	Land m^2 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 Table 3, 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 on 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.

3. Results and Discussion

3.1. 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. P=1-2-3-4...28 scenarios are examined. 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 ($) and the cost of opening a warehouse ($) was taken into account in the model.

IBM ILOG CPLEX program is frequently used in operations research for solving mathematical models (Gürbüz, 2020). Various tools and programs are used to optimize warehouse location problems. It is one of some programs used in CPLEX (Ersen & Sel 2020).

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 indicates the number of warehouses to be opened on the smaller table. 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.

The planned warehouse locations and numbers have been considered in 28 different scenarios. The Table 4 below shows the comparison of 28 different scenarios.

Table 4. 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 objective solution graph was drawn in Figure 3 in line with the total distance traveled and the total cost.

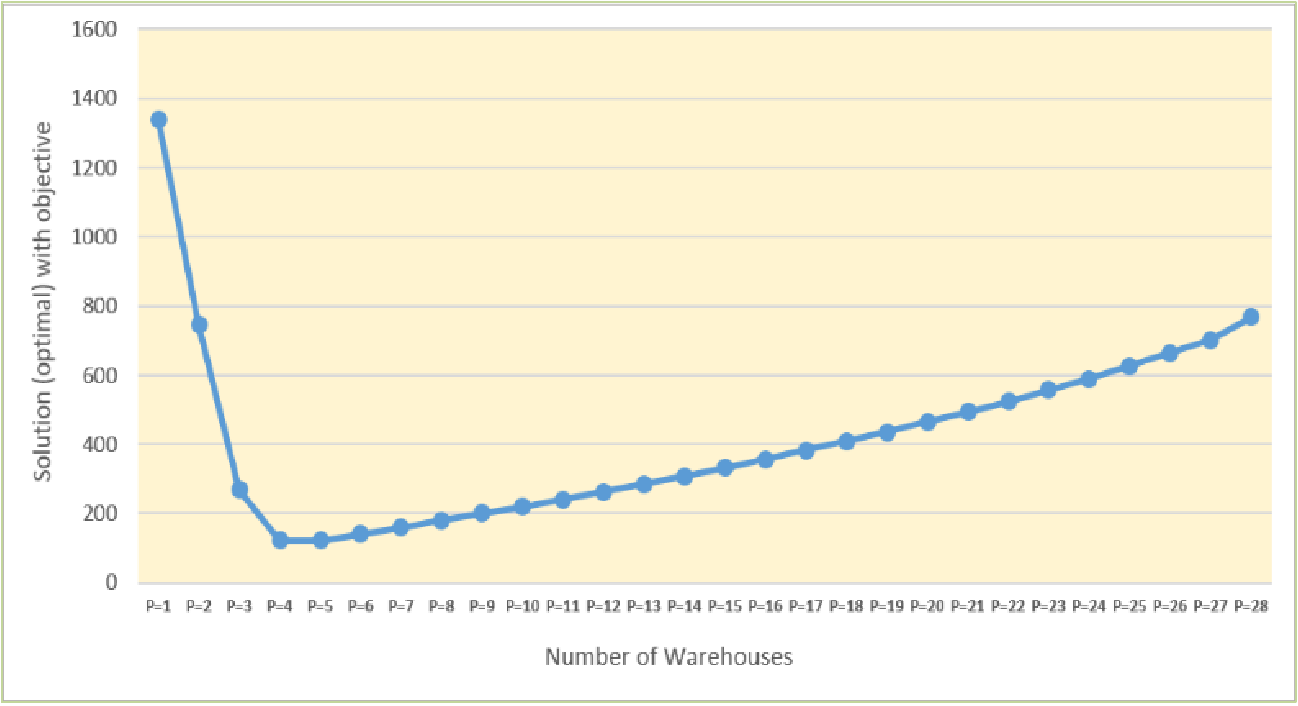

Figure 3. Number of Warehouses - Optimal Objective Solution (Ersen & Sel 2020)

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 warehouse will be established in Adana Saricam, Ankara Yenimahalle, Istanbul Tuzla, Izmir Cigli, and Konya Selcuklu. Figure 4 shows the places where warehouses are to be established.

Figure 4. Places Where It is Foreseen to Establish Warehouse (https://earth.google.com)

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.

1. Adana Saricam: Adana, Diyarbakir, Elazig, Erzurum, Gaziantep, Hatay, Mersin, Malatya, Mardin, Urfa, Van
2. Ankara Yenimahalle: Ankara, Eskisehir, Ordu, Samsun, Trabzon, Zonguldak
3. Istanbul Tuzla: Bursa, Istanbul, Kocaeli, Sakarya
4. Izmir Cigli: Denizli, Izmir, Manisa, Mugla
5. Konya Selcuklu: Antalya, Kayseri, Konya

3.2. Distribution of Processing Facilities and Warehouses

Looking at the distribution of licensed electronic 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. As can be seen in Figure 5, warehouses have been established as a result of optimization in places close to the provinces where processing facilities are concentrated.

Figure 5. Distribution of Processing Facilities and Warehouses
(Turkey Ministry of Environment and Urbanization, Provincial Status Reports)

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

Compared to the warehouses that have 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 in a province with a larger population, it is possible to produce much more waste in a low population. Therefore, the number of individuals per unit multiplied by the amount of waste was entered into the model as a demand parameter. It is aimed at determining the most suitable places for creating 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:

$$Min \sum_{i=1}^{n} \sum_{j=1}^{n} a_i.w_i.d_{ij}.X_{ij} \quad (6)$$

Constraints:

$$\sum_{i=1}^{n} Y_i \leq P_{max} \qquad \forall i,j = 1,2 \dots, n \quad (7)$$

$$\sum_{i=1}^{n} X_{ij} \geq 1 \qquad \forall i,j = 1,2 \dots, n \quad (8)$$

$$\sum_{i=1}^{n} Y_i \geq 1 \qquad \forall i,j = 1,2 \dots, n \quad (9)$$

$$X_{ij} \leq Y_i \qquad \forall i,j = 1,2 \dots, n \quad (10)$$

$$X_{ij}, Y_j \in \{0,1\} \qquad \forall i,j = 1,2 \dots., n \quad (11)$$

In the study, the objective function expressed in equation (6) 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. Y_i refers to the creation or non-creation of waste collection boxes. The maximum number of collection boxes to be opened, the P_{max} =28 constraint is also given in equation (7). Equation (8) is the constraint that more than one waste collection box can receive services from a warehouse. Equation (9) is the constraint of creating at least one waste collection box. Equation (10) every waste collection box must receive service from the opened warehouse places. In equation (11), 0,1 is the condition of being an integer.

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

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

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 Table 5.

Table 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 has 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.

The optimal solution graph Figure 6 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. The optimal solution is 35823387050. CPU solution time of the problem is 4.368028 seconds.

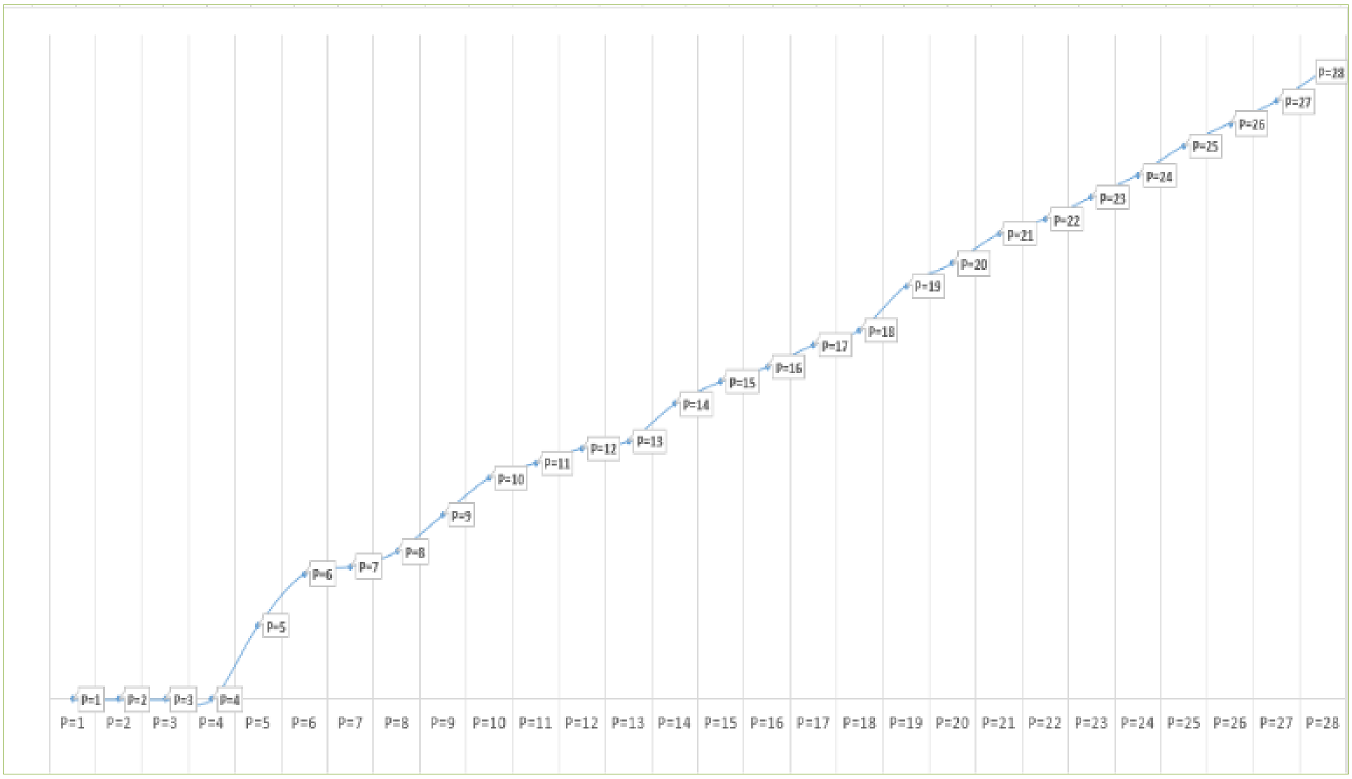

Figure 6. Waste Collection Box Optimal Solution (Ersen & Sel 2020)

4. Conclusions and Recommendations

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

As a result of this study, a detailed literature study was made by examining the electronic waste management practices applied in our country and internationally. The current situation and emerging problems in Turkey are discussed. Within the scope of the study, the most optimal warehouse location was determined to establish a waste collection center (warehouse) for electronic waste that is 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. 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 that have 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. 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).

For 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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