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A Mixed Integer Linear Programming Model for End of Life Vehicles Recycling Network Design

Sezin Balcı[a] , Berk Ayvaz[b]

[b] Istanbul Commerce University, Graduate School of Natural and Applied Sciences, Küçükyalı E5 KavşağıInönü Cad. No: 4, Maltepe 34840, Istanbul, Turkey

[a]sezinbbalci@gmail.com , [b]bayvaz@ticaret.edu.tr

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Abstract

Automotive industry, with both its contributions to the technology and values added to the economy, has been indisputably one of the leading sectors. As the demand and interest in automobile grow, the environmental pollution caused by the automobiles increases correspondingly. In addition to automobiles' carbon emissions, also the vehicles which have completed their life cycle, namely scrap vehicles, cause environmental pollution due to their solid and liquid waste. In developed countries, a regulation has been made in order to prevent the situation from getting worse. According to this regulation, in order to support product management, manufacturers are obliged to take back and recycle all their vehicles which have completed their life cycle. The regulation started to be implemented after being adapted to the national law. Upon its adaptation to our national regulations, it has been enforced in our country as well.

In the study, Mixed Integer Linear Programming (MILP) model has been presented to design end of life vehicles recycling network. The proposed model has minimized the total network cost as well as to determine the amount of material transported between the facilities and to decide whether to open the dismantling and shredding facilities. The presented model has been applied to end of life vehicles recycling network design problem in Istanbul. The proposed model gives suitable and cost effective results for end of life vehicles recycling network in Istanbul.

1. INTRODUCTION

The automotive sector is one of the world's leading economic activities with its high share in global trade, production and job creation capacity [1]. Significant growth in Turkish automotive sector led Turkey to become the world's 15th largest and Europe's 5th largest automotive producer by the end of 2015 [2].

Increasing environmental awareness and threat of global warming are among important dynamics that will determine the direction of the automotive industry. In recent years, it has been observed that a number of developed or developing countries brought strict rules to environmental standards [2].

The EU Directive has developed a regulation mandating automobile manufacturers all over the world to take financial responsibility for appropriate environmental management of vehicles that completed their life cycle [3]. With this regulation, it is considered that the aim of the producer companies is to produce eco-friendly products and to take the responsibility of the products that completed their life cycle for the sake of customer awareness, social responsibility and economic benefits [4]. The regulation developed by the EU Directive has been harmonized with the national legislation in our country.

The regulation harmonized with the national legislation has been published by the Ministry of Environment and Urbanization in the official newspaper in number 27448 under the name of the Directive on the Control of End of Life Vehicles (ELV). The directive has been issued to prevent the generation of waste caused by vehicles, reduce the amount of waste that is emitted to the environment through reusing, recycling and recovery operations of vehicles and parts of vehicles that completed their life cycle [5].

When the amount of hazardous waste produced by the industry is analyzed, it is measured that the amount of hazardous waste is 11 kg per automobile, 326 kg per bus, 77 kg per truck [6].

The EU directive on ELVs has determined targets for 2006 and 2015 years that contain recycling-reuse and recovery-reuse rate of ELV's. The target for energy recovery in the directive has also been determined. It has been aimed that 5% of ELVs for 2006 and 10% of ELVs for 2015 will not be used for energy recovery. These targets are listed in Table 1 [7].

Table 1. Targets Determined in the European Union's End of Life Vehicles Directive [7]

European Union Target Dates	Recovery and Reuse (%)	Total Recovery, Recycling& Reuse (%)
2006	%80	% 85
2015	%85	% 95

Directive on the Control of ELVs in Turkey, by the 2020, aims to achieve that the reuse-recovery rates of ELVs are at least 95% of the average vehicle weight and the reuse-recycling rate is at least 85% of the average vehicle weight.

In order to increase the fuel efficiency of a typical vehicle, changes have been made in the materials used in production. The light weight plastic components found in the vehicle have replaced the metal components over time. These trend lines are shown in Table 2.The economic recovery of ELVs and ELV materials and components or the proper disposal of ineffective ELV materials and components, are achieved through reverse logistics.

In the scope of this study, it took the basis of carrying out efficient recovery processes of the vehicles that have completed their life cycles in Istanbul. A model has been developed to minimize the total system cost, to determine the amount of material transported between the facilities, to decide whether to open the reprocess/disassembly and rescue facilities. This model is formulated by using the Mixed Integer Linear Program (MILP).

The second part of the study summarizes the studies in the literature about ELVs reverse logistics. In the third part, the problem is introduced, the methodology of study is mentioned and the mathematical formulation is realized. In the fourth part, performed sample implementation is summarized. Finally, in the fifth part, the results of the study are presented and sensitivity analysis is included.

Table 2. Composition of a Typical ELV Over Time

Material	2006 (kg)	2015 (kg)
Ferrous Metal	680	650
Non Ferrous Metal	80	90
Plastic vs Process Polymers	100	120
Tires	30	30
Glass	30	30
Batteries	13	13
Fluids	17	17
Textiles Materials	10	10
Rubber	20	20
Others	20	20
Total	1000	1000

2.LITERATURE REVIEW

The environmental impacts of ELVs and ELV residues are worrying around the world. The laws for the recycling of ELVs are applied in many countries. Therefore, with the implementation of the law, the number of researches on the recycling of ELVs has increased.

Schultmann, Zumkeller, &Rentz [13, 14], proposed a closed-loop supply chain model for the end-of-life vehicle treatment in Germany. They focused on vehicle routing planning especially. Cruz-Rivera &Ertel [15], presented an incapacitated facility location problem for the collection of End-of-Life Vehicles in Mexico. Zarei, Mansour, Kashan, &Karimi [16], designed a reverse logistics network for the ELVs recovery process. The aim of the proposed model is to minimize he costs of collecting the ELVs and flow of materials between facilities. Genetic algorithm approach is used for solving the model. Harraz&Galal [17], presented a mixed integer goal programming model to design a sustainable recovery network for ELVs in Egypt. The proposed model includes locations for the different facilities and the amount of allocation to the different end of life options. Vidovic, Dimitrijevic, Ratkovic, &Simic [18], presented a maximal covering location model to establish a reverse logistics network for ELVs by defining optimum locations for collection points. The developed model was illustrated on the Belgrade city area. Farel, Yannou, Ghaffari, & Leroy [19], used system dynamics simulation approach to model ELV glazing recycling network in France under different scenarios. Gołebiewski, Trajer, Jaros, &Winiczenko [20], developed a model for end-of-life vehicles (ELVs) by defining the optimum locations for dismantling facilities. The proposed model is applied to Mazovia province in Poland. Because of the high complexity of the presented model, a genetic algorithm has been used for solving the model.

Mahmoudzadeh, Mansour, &Karimi [21], proposed a MILP model to determine optimal locations of scrap yards over the Iran as well as their optimal allocations and material flows. In this study, ELVs are categorized in three quality levels with different output material streams. Farel et al. [22], propose linear programming model to determine configuration and material flow sizing of the future ELV glazing recycling network in France.

Ene&Öztürk [5], presented a mathematical programming model for managing reverse flows disassembly, refurbishing, shredding, recycling, disposal and reuse of vehicle parts. The scope of the network model is to determine the numbers and locations of facilities in the network and the material flows between these facilities. Simic [23], proposed a two-stage interval-stochastic programming model for management of ELV allocation under uncertainty. It is made various policy scenarios dealing with different levels of economic penalties in terms of ELV allocation targets. The proposed model was applied to a hypothetical case study. Chen et al. [24], apply dynamic modelling and cost- benefit analysis to investigate how polices may affect recycling of ELVs in China and outline that parameter uncertainty should be further explored. Demirel, Demirel, &Gökçen [25], proposed a mixed integer linear programming model for ELV network design. The proposed framework is applied to a real case study in Ankara. Simic [26], presented a multi-stage interval-stochastic programming model for planning end-of-life vehicles allocation. The developed model is able to reflect dynamics in terms of decisions for ELV allocation from a multi-region waste management system to multiple vehicle recycling factories within a multi-period context. Uncertain parameters are expressed by using probability distributions and discrete intervals. Özceylan, Demirel, Çetinkaya&Demirel [27], has developed a linear programming model to reintegrate the backward material flow with the forward supply chain and investigated the performance and applicability of the model by creating various scenarios.

Starting from these researches, a mixed linear programming model was developed for the efficient management of ELV recycling processes in Istanbul and the required responsibilities were met with minimum cost and complied with the related regulations, and reverse logistics network design was made.

3. RESEARCH METHODOLOGY

In this study, we used mixed integer linear programming model because of the fact that some of variables which will be used in the model are integer values (0,1) and some are continuous variable values.

In order to implement a mixed integer linear programming model, stages that need to be completed are shown in Figure 1.

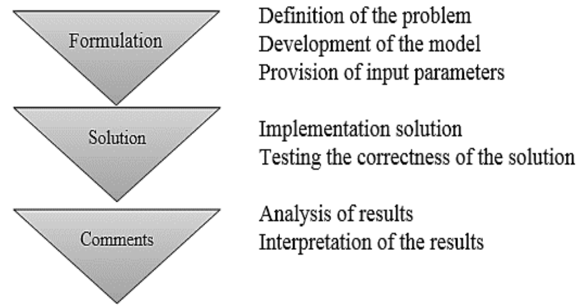

Figure 1: Installation Phases of Mixed Integer Linear Programming Model [31]

The representation of the mixed integer programming problem is as follows:

min: $ax + by$

constraints: $Cx + Dy \geq b$

$x \geq 0$

$y \geq 0$ *and is integer.*

It is shown that x is the vector of continuous variables, a is the coefficient vector in the objective function of x and c is the coefficient matrix in the constrains of x.

This study addresses a network design problem for cost minimization as well determining to open or not to open the facilities, and materials are transferred from the opened facilities. The distances between the facilities is estimated via Euclidean Relation Method. Facility locations are mapped with scalable integrated geographic information system software which is called ArcGIS 10. For the solution model, GAMS 23.5.1 (General Algebraic Modeling System) program was used and the optimal result was reached. Sensitivity analysis has been performed for the problem that has been solved. It has been researched how the solutions will be affected depends on the system parameters changes.

3.1. Problem Definition

The reverse logistics network for ELVs begins with the transfer of vehicles whose life has been completed, from ELV source points to licensed vehicle collectors or authorized dismantling facilities. For the ELVs arriving at the authorized dismantling facility or the licensed vehicle collector, the registration deletion and disposal form approved by the traffic registration is filled out. So the vehicle is legally deregistered from the traffic.

ELVs arriving at licensed vehicle collectors are sent directly to the authorized dismantling facility without any processing. Fluids (fuel, engine oil, transmission oil, hydraulic oil, coolant, air conditioning fluid, brake fluid, steering fluid etc.) of the ELVs coming to the authorized dismantling facility are drained and then the dismantling process is carried out. Materials such as the plastic, glass obtained as a result of the dismantling process are sent to the recycling facility and the ELV body is called a hulk and sent to reprocessing/shredding facility to be broken into pieces. As a result of the dismantling process, some valuable and reusable parts also emerge. Engines, differentials, transmissions, body panels (covers, doors, bumpers), wheels are reusable and valuable pieces and can be sold in secondary markets. Ferrous and non-ferrous metals and ASRs which are obtained as a result of the shredding process applied to the vehicle body, which is called Hulk. ASRs, referred to as vehicle parts residues, are transferred to the disposal facility for disposal. Ferrous and non-ferrous metals are transported to the recycling facility. Materials that have been transferred from the competent dismantling facilities and the reprocess/shredding facilities to the recycling facilities are subjected to the recycling process. The recycled raw materials are transferred to the suppliers. Hazardous and toxic wastes that cannot be recovered are transferred to the disposal facilities like ASRs and disposal of them. The recycling process of ELVs is shown in Figure 2.

The proposed mathematical model includes the following assumptions:

- All ELVs must be collected.
- ELV source points must send their ELV to licensed vehicle collection centers or authorized dismantling facilities.
- The capacities of all facilities are limited and stable.
- The materials to be transported are divisible quantities which can be applied in units of weight.
- Inventory or accumulated order is not allowed due to the capacity which is sufficient for requests.
- The coefficients of the objective function are deterministic and known in advance.
- Weight percentages related to reverse flow are known.
- 39 district of Istanbul Province are accepted as ELV source points.
- The authorized dismantling facility and the reprocessing/shredding facility are considered as candidate areas. The selection of the final location is made from among the potential locations.

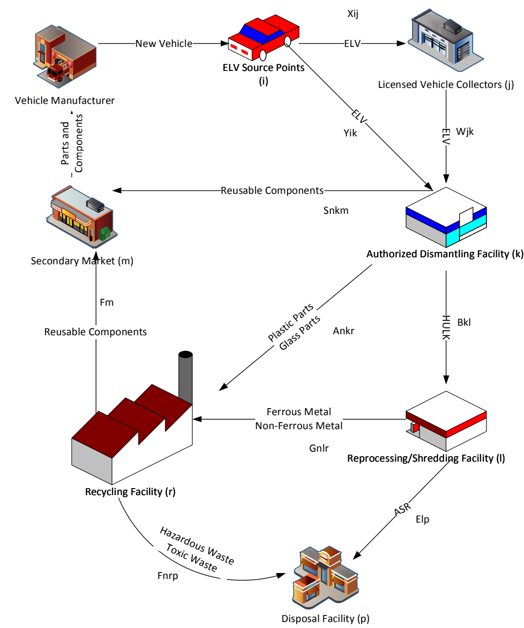

Figure 2. ELV Recycling Process

3.2.The ProposedMathematical Model

The objective function of the proposed MILP model consists of the transportation cost of ELVs and ELV parts, the transaction cost (collection, dismantling, reprocessing/shredding, recycling, disposal) and the facility constant opening costs. The sale of reusable metals and recycled raw materials has not been evaluated in the objective function. Transportation costs of ELVs transported from ELV source points to licensed vehicle collectors or authorized dismantling facilities are ignored in the objective function.

The proposed model is formulated as following:

Indexes:

n:	Component/Material series	n:1,2,3…N
i:	ELV source point	i:1,2,3…I
j:	Licensed vehicle collection center	j:1,2,3…J
k:	Authorized dismantling facility	k:1,2,3...K
l:	Reprocessing/Shredding facility	l:1,2,3...L
p:	Disposal facility	p:1,2,3…P
r:	Recycling facility	r:1,2,3…R
m:	Secondary market	m:1,2,3…M

Parameters:

Z_i: amount of ELV returned from ELV source point i (ton)

The Fixed Opening Cost

f_l: the fixed opening cost for reprocessing/shredding facility l (TL)

f_k: the fixed opening cost for authorized dismantling facility k (TL)

The Process Cost

dc_k: unit cost of dismantling at authorized dismantling facility k (TL/ton)

sc_l: unit cost of shredding at reprocessing/shredding facility l (TL/ton)

lc_p: unit cost of disposal at disposal facility p (TL/ton)

rc_r: unit cost of recycling at recycling facility r (TL/ton)

The Transportation Cost

t_{jk}: unit cost of transportation between licensed vehicle collection center j and authorized dismantling facilities k for ELV (TL/ton*km)

t_{kr}: unit cost of transportation between authorized dismantling facility k and recycling facility r for components and materials (TL/ton*km)

t_{kl}: unit cost of transportation between authorized dismantling facility k and reprocessing/shredding facility l for hulk (TL/ton*km)

t_{lr}: unit cost of transportation between reprocessing/shredding facility l and recycling facility r for components and materials (TL/ton*km)

t_{lp}: unit cost of transportation between reprocessing/shredding facility l and disposal facility p for ASR (TL/ton*km)

t_{rp}: unit cost of transportation between recycling facility r and disposal facility p for components and materials (TL/ton*km)

t_{rm}: unit cost of transportation between recycling facility r and secondary market m for components and materials (TL/ton*km)

The Transportation Distances

d_{jk}: distance between licensed vehicle collection center j and authorized dismantling facility k (km)

d_{kl}: distance between authorized dismantling facility k and reprocessing/shredding facility l (km)

d_{kr}: distance between authorized dismantling facility k and recycling facility r (km)

d_{lr}: distance between reprocessing/shredding facility l and recycling facility r (km)

d_{lp}: distance between reprocessing/shredding facility l and disposal facility p (km)

d_{rp}: distance between recycling facility r and disposal facility p (km)

d_{km}: distance between authorized dismantling facility k and secondary market m (km)

d_{rm}: distance between recycling facility r and secondary market m (km)

Capacities

cap_j: capacity of licensed vehicle collection center j (ton)

cap_k: capacity of authorized dismantling facility k (ton)

cap_l: capacity of reprocessing/shredding facility l (ton)

cap_{nr}: capacity of recycling facility r (ton)

cap_p: capacity of disposal facility p (ton)

Other Parameters

$a1$: weight percentage of hulk in ELV

$a2$: weight percentage of ASR in hulk

$a3$: weight percentage of reusable component/material n in ELV

$a4$: weight percentage of non-reusable component/material in ELV

$a5$: weight percentage of recyclable material n in hulk

$a6$: weight percentage of disposal n in recyclable material

Decision Variables:

X_{ij}: amount of ELV shipped from ELV source point i to licensed vehicle collection center j

Y_{ik}: amount of ELV shipped from ELV source point i to authorized dismantling facility k

W_{jk}: amount of ELV shipped from licensed vehicle collection center j to authorized dismantling facility k

S_{nkm}: amount of reusable component/material n shipped from authorized dismantling facility k to secondary market m

A_{nkr}: amount of non-reusable component/material n shipped from authorized dismantling facility k to recycling facility r

B_{kl}: amount of hulk shipped from authorized dismantling facility k to reprocessing/shredding facility l

G_{nlr}: amount of material n shipped from reprocessing/shredding facility l to recycling facility r

E_{lp}: amount of ASR shipped from reprocessing/shredding facility l to disposal facility p

F_{nrp}: amount of disposal n shipped from recycling facility r to disposal facility p

F_{m}: amount of reusable component/material n shipped from recycling facility r to secondary market m

e_l: if reprocessing/shredding facility l is opened 1; otherwise, 0

e_k: if authorized dismantling facility k is opened 1; otherwise, 0

Objective Function (Minimize):

$$\sum_l f_l \cdot e_l + \sum_k f_k . e_k \qquad [1]$$

$$\sum_i \sum_j X_{ij}.t_{ij}.d_{ij} + \sum_i \sum_k Y_{ik}.t_{ik}.d_{ik} + \sum_j \sum_k W_{jk}.t_{jk}.d_{jk} + \sum_n \sum_k \sum_r A_{nkr}.t_{kr}.d_{kr} + \sum_k \sum_l B_{kl}.t_{kl}.d_{kl} + \sum_n \sum_l \sum_r G_{nlr}.t_{lr}.d_{lr} + \sum_n \sum_k \sum_m S_{nkm}.t_{km}.d_{km} + \sum_l \sum_p E_{lp}.t_{lp}.d_{lp} + \sum_n \sum_r \sum_p F_{nrp}.t_{rp}.d_{rp} + \sum_n \sum_r \sum_m F_m.t_{rm}.d_{rm} + \quad [2]$$

$$\sum_i \sum_j X_{ij}.cc_j + \sum_i \sum_k Y_{ik}.cc_k + \sum_j \sum_k W_{jk}.cc_k + \quad [3]$$

$$\sum_j \sum_k W_{jk}.dc_k + \sum_i \sum_k Y_{ik}.dc_k + \quad [4]$$

$$\sum_k \sum_l B_{kl}.sc_l + \quad [5]$$

$$\sum_n \sum_k \sum_r A_{nkr}.rc_r + \sum_n \sum_l \sum_r G_{nlr}.rc_r + \quad [6]$$

$$\sum_l \sum_p E_{lp}.lc_p + \sum_n \sum_r \sum_p F_{nrp}.lc_p \quad [7]$$

Constraints:

$$\sum_j X_{ij} + \sum_k Y_{ik} = Z_i \quad \forall i \quad [8]$$

$$\sum_i X_{ij} = \sum_k W_{jk} \quad \forall j \quad [9]$$

$$\sum_l B_{kl} = a1.ratio(n).\left(\sum_i Y_{ik} + \sum_j W_{jk}\right) \quad \forall k \quad [10]$$

$$\sum_m \sum_n S_{nkm} = a3.\left(\sum_i Y_{ik} + \sum_j W_{jk}\right) \quad \forall k \quad [11]$$

$$\sum_r A_{nkr} = a4.ratio(n).\left(\sum_i Y_{ik} + \sum_j W_{jk}\right) \quad \forall k,n \quad [12]$$

$$\sum_p E_{lp} = a2.\left(\sum_k B_{kl}\right) \quad \forall l \quad [13]$$

$$\sum_r G_{nlr} = a5.\sum_k B_{kl} \quad \forall l,n \quad [14]$$

$$\sum_p F_{nrp} = a6.\left(\sum_k A_{nkr} + \sum_l G_{nlr}\right) \quad \forall r,n \quad [15]$$

$$\sum_i X_{ij} \le cap_j \quad \forall j \quad [16]$$

$$\sum_i Y_{ik} + \sum_j W_{jk} \le cap_k.e_k \quad \forall k \quad [17]$$

$$\sum_k B_{kl} \le cap_l.e_l \quad \forall l \quad [18]$$

$$\sum_k A_{nkr} + \sum_l G_{nlr} \le cap_{nr} \quad \forall r,n \quad [19]$$

$$\sum_l E_{lp} + \sum_r F_{nrp} \le cap_p \quad \forall p,n \quad [20]$$

$$X_{ij}, Y_{ik}, W_{jk}, S_{nkm}, A_{nkr}, B_{kl}, G_{nlr}, E > 0 \quad \forall i,j,k,m,r,l,p, \quad [21]$$

$$e_k.e_l = \{0,1\} \quad \forall k,l \quad [22]$$

The objective function has seven components. The first component represents the fixed costs associated with locating authorized dismantling facility and reprocessing/shredding facilities [1]. The second component represents the cost of transportation on each arc of the network [2]. The third component represents the collection cost of the ELVs [3]. The fourth component represents the disposal cost of the ELVs sent to the authorized dismantling facility [4]. The fifth component represents the shredding cost of the Hulk sent to the reprocessing/shredding facility [5].The sixth component represents the recycling cost of materials sent to the recycling facility [6]. Finally, the seventh component represents the disposal cost of ASRs sent to the disposal facility [7]. Constraint [8] determines the returned quantities of ELV from ELV source points to the licensed vehicle collection centers and the authorized dismantling facilities. Constraint [9] is the balance equation for licensed vehicle collection centers. The constraint [10] is the restriction that the amount of hulk transported from the authorized dismantling facilities to the reprocessing/shredding facilities is equal to the amount of

Hulk generated after the dismantling of the ELVs transported from the licensed vehicle collectors and ELV source points to the authorized dismantling facilities. Constraint [11] is a restriction that the amount of reusable component/material transported from the authorized dismantling facilities to the secondary markets is equal to the amount of reusable component/material generated after disassembly of the ELVs transported from the licensed vehicle collectors and ELV source points to the authorized dismantling facilities. The constraint [12] is a restriction that the amount of non-reusable component/material transported from the authorized dismantling facilities to the recycling facilities is equal to the amount of non-reusable component/material generated after disassembly of the ELVs transported from the licensed vehicle collectors and ELV source points to the authorized dismantling facilities. The constraint [13] is a restriction that the amount of ASR transported from the reprocessing/shredding facilities to the disposal facilities is equal to that of ASR generated after shredding of hulk transported from the authorized dismantling facilities to the reprocessing/shredding facilities. The constraint [14] is a restriction that the amount of ferrous and non-ferrous metal transported from the reprocessing/shredding facilities to the recycling facilities is equal to the amount of ferrous and non-ferrous metal generated after shredding of hulk transported from the authorized dismantling facilities to the reprocessing/shredding facilities. The constraint [15] is a restriction that the amount of hazardous and toxic waste transported from the recycling facilities to the disposal facilities is equal to the that of hazardous and toxic waste generated after recycling of component/material transported from authorized dismantling facilities and the reprocessing/shredding facilities to the recycling facilities. Constraints [16-20] stipulate that the transportation amounts must not exceed the capacity of licensed vehicle collectors, authorized dismantling facilities, reprocessing/shredding facilities, recycling facilities and disposal facilities at each period, respectively.Constraint [21] enforces the non-negativity restriction on the decision variables.Finally, the constraint [22] ensures that the values that the facilities opening decision variable can take are 0 or 1.

4. APPLICATION

The aim of this study is to define the recycling network parameters of vehicles which completed their lifecycle and to solve them with minimum cost within the scope of the ELV Directive in İstanbul. The required data for ELV reverse logistics network model is provided by Turkish Statistical Institute and the Ministry of Environment and Urban Planning of the Republic of Turkey. For recycling of end of life vehicles, the total number of automobiles in category M1 has been taken into account. It is assumed that the average weight of M1 ELVs is 1000 kg.

Istanbul is located in the north-west of Turkey between 280 01' and 290 55' east longitudes and 410 33' and 400 28' north latitudes. It is the most crowded and important city economicallyand socio-culturally in the country. According to the Turkish Statistical Institute, as of the end of 2016, the population of Istanbul is 14.804.116. Due to the large population of people residing in Istanbul, the number of vehicles registered in traffic in Istanbul and deregistered from traffic is higher than that in other cities. According to data of Turkish Statistical Institute, as of the end of 2016 in Istanbul, the number of vehicles registered to traffic is 3.875.145. 69% of this number belongs to automobiles. It is 2.669.296. In Figure 3, graphically on the total number of vehicles and automobiles deregistered from traffic in Istanbul between 2005 and 2016 is shown.

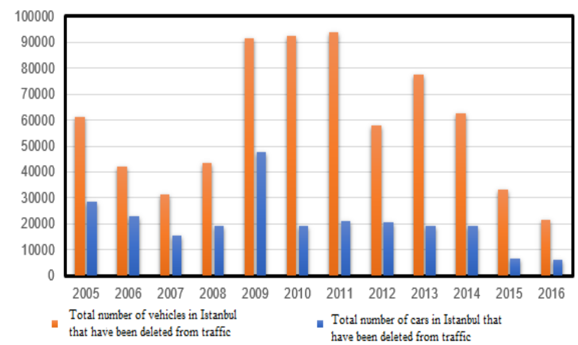

Figure 3. Number of Vehicle and Automobile Deregistered from Traffic between 2005 and 2016

There are 39 districts belonging to the province of Istanbul and all of them are determined as ELV source. Organized industrial zones and auto industry sites operating in Istanbul were taken into consideration as secondary markets. Therefore, 29 secondary markets were assumed in Istanbul. Table 4 shows ELV numbers for the districts of Istanbul according to the proportion to the district population in Istanbul.

The average number of automobile numbers deregistered from traffic in Istanbul covering the years 2012-2016 is given in Figure 4. In İstanbul, number of automobile numbers deregistered from traffic covering the years 2012-2016 is 14.379. Based on the year 2016 districts population data, the average ELV numbers for the last 5 years have been distributed to the counties. These data can be accessed from Table 3.

According to data of the Ministry of Environment and Urban Planning of the Republic of the Turkey in 2016, there are 52 licensed vehicle collectors, 5 authorized dismantling facilities, 4 reprocessing/shredding facilities, 3 recycling facilities and 2 disposal centers.

In Figure 4, it is seen that in the recycling network for ELVs in Istanbul, licensed vehicle collectors, authorized dismantling facilities, reprocessing/shredding facilities, recycling facilities and disposal facilities. The locations of the facilities are mapped with the scalable integrated geographic information system software which is named ArcGIS 10.

Euclidean distance method was used for distances between facilities and distances were calculated. The weight ratios of the components present in the ELV with a total weight of 1000 kilograms are 0,65; 0,09; 0,12; 0,03; 0,03; 0,013; 0,017; 0,05.These ratios are ferrous metal (n1), non-ferrous metal (n2), plastic (n3), rubber (n4), glass (n5), battery (n6), fluids (n6) and other materials (n7) respectively. In addition, the hulk weight percentage (a1) in the ELV is 0.810, the weight percentage (a2) of the ASR in the hulk is 0.185, the reusable weight percentage (a3) of the material n in the ELV is 0.137, The non-recyclable weight percentage (a4) of the material n in the ELV is 0.864, the recycled weight percentage (a5) of the material n in the hulk is 0.815, and the percent disposal weight (a6) in the recycled n material is 0.15. The opening costs of the authorized dismantling facilities and the reprocessing/shredding facilities are set at 630.000 TL and 2.500.000 TL respectively. Transaction cost for all authorized dismantling facilities; 980 TL/ton, transaction costs for reprocessing /shredding facilities; 135 TL/ton, transaction costs of recycling plants; 500 TL/ton and the transaction costs of the disposal centers are 250 TL/ton.

Table 3. Districts of Istanbul Province and Population-Based ELV Amounts

Districts	Latitude	Longitude	Population	ELV
Adalar	40.877888	29.089782	14.478	14
Arnavutköy	41.240101	28.642005	247.507	240
Ataşehir	40.983535	29.127746	422.513	410
Avcılar	40.982205	28.720328	430.770	419
Bağcılar	41.045638	28.836723	751.510	730
Bahçelievler	40.997719	28.850524	598.097	581
Bakırköy	40.968317	28.822832	222.437	216
Başakşehir	41.086518	28.775242	369.810	359
Bayrampaşa	41.050844	28.901213	273.148	265
Beşiktaş	41.075594	29.026280	189.356	184
Beykoz	41.132889	29.105679	250.410	243
Beylikdüzü	40.989202	28.654232	297.420	289
Beyoğlu	41.037171	28.977511	238.762	232
Büyükçekmece	41.048110	28.451656	237.185	230
Çatalca	41.141889	28.460900	68.935	67
Çekmeköy	41.063939	29.243649	239.611	233
Esenler	41.058428	28.864317	457.231	444
Esenyurt	41.041533	28.694037	795.010	773
Eyüp	41.055227	28.934401	377.650	367
Fatih	41.019635	28.934572	417.285	405
Gaziosmanpaşa	41.076631	28.888226	499.766	486
Güngören	41.023010	28.875366	298.509	290
Kadıköy	40.990458	29.054813	452.302	439
Kağıthane	41.088974	28.981015	439.685	427
Kartal	40.905018	29.174769	459.298	446
Küçükmece	41.036977	28.776066	766.609	745
Maltepe	40.951173	29.144557	490.151	476
Pendik	40.915796	29.300535	691.681	672
Sancaktepe	41.007395	29.207393	377.047	366
Sarıyer	41.163520	29.047396	342.753	333
Şile	41.169069	29.608533	34.241	33
Silivri	41.066167	28.066211	170.523	165
Şişli	41.060230	28.988132	272.803	265
Sultanbeyli	40.979397	29.268199	324.709	315
Sultangazi	41.113391	28.855865	525.090	510
Tuzla	40.875535	29.332648	242.232	235
Ümraniye	41.046154	29.108367	694.158	675
Üsküdar	41.040665	29.068670	535.537	520
Zeytinburnu	41.003851	28.907630	287.897	280

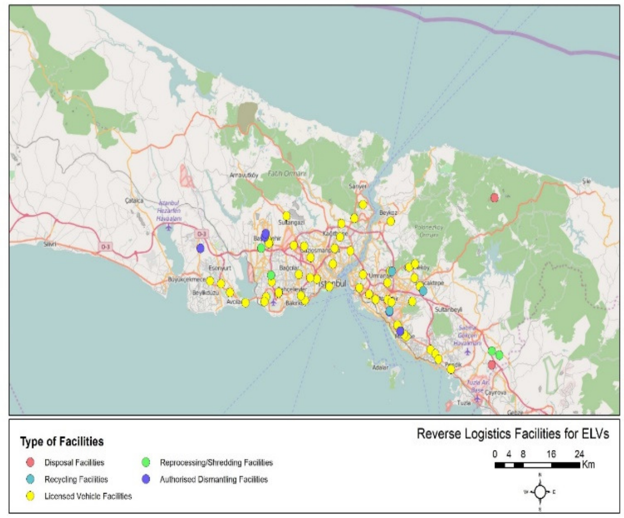

Figure 4. Facilities in ELV Recycling Network and Their Locations

Detailed information has not been obtained from the existing facilities in the relevant facilities in Istanbul regarding licensed vehicle collectors, authorized dismantling facilities, reprocessing /shredding facilities, recycling facilities and disposal facility capacities.Therefore, industrial investigations and literature reviews were made for facilities capacity estimates and the estimates are assumed to be accurate.Facilities capacities in the model; 1.000 tons for licensed vehicle collector, 5.000 tons for authorized dismantling facilities, 15.000 tons for reprocessing/shredding facilities and 10.000 tons for disposal facilities.For the recycling facilities, 1,726 tons of capacity was allocated to the battery, 5,910 tons of capacity was reserved for the fluids, and 2,364 tons of capacities were allocated to the tires.

5. SOLUTIONS

The problem was solved using GAMS 23.5.1 and processed with a server with 2.40 GHz Intel Core Processor and 8 GB RAM.The calculation time required for the optimal solution was determined to be 15 CPU seconds.

The optimal solution value for the problem was determined to be 96.526.930 TL. It has been decided that 3 of the authorized dismantling facilities (2nd, 4th and 5th) and 2 of the reprocessing/shredding facilities (2nd and 3rd) should be opened for the most appropriate solution. The optimal values of the decision variables are shown in Table 5. It is also possible to see from Table 4 that ELVs and ELV parts and components are subjected to the processing through the which facilities in the recycling network. As shown in Table 5, the ELVs are transported to licensed vehicle collectors with number 11, 25, 26, 28, 35, 37, 39, 41, 44, 49 and 50. There is no transportation between ELV source points and other licensed vehicle collectors.ELVs were transported to the licensed vehicle collectors numbered 26, 35, 41, 44 from the ELV source points and 1000 of ELV have been transported to each one. The minimum amount of ELV has been transferred to the licensed vehicle collector with number 11.

Table 4. Results for GAMS 23.5.1 Program's ELV Recycling Network

Variable	Value	Variable	Value	Variable	Value
$X_{1,50}$	10	$X_{38,50}$	364	$W_{28,4}$	1.000
$X_{2,11}$	118	$X_{39,49}$	65	$W_{35,4}$	1.000
$X_{2,39}$	16	$X_{39,50}$	131	$W_{37,2}$	1.000
$X_{2,44}$	34	$Y_{1,2}$	4	$W_{39,4}$	1.000
$X_{3,44}$	157	$Y_{2,2}$	72	$W_{41,2}$	1.000
$X_{3,49}$	130	$Y_{3,5}$	123	$W_{44,4}$	1.000
$X_{4,49}$	293	$Y_{4,5}$	126	$W_{49,5}$	1.000
$X_{5,49}$	511	$Y_{5,5}$	219	$W_{50,2}$	1.000
$X_{6,44}$	407	$Y_{6,5}$	174	$S_{1,2,11}$	675
$X_{7,44}$	151	$Y_{7,2}$	65	$S_{2,5,11}$	675
$X_{8,44}$	251	$Y_{8,2}$	108	$S_{3,4,13}$	591,16
$X_{9,39}$	37	$Y_{9,2}$	80	$A_{3,2,1}$	33
$X_{9,41}$	148	$Y_{10,2}$	55	$A_{3,4,1}$	28,901
$X_{10,39}$	129	$Y_{11,2}$	73	$A_{3,5,1}$	33
$X_{11,39}$	170	$Y_{12,2}$	87	$A_{4,2,1}$	8,250
$X_{12,39}$	202	$Y_{13,2}$	70	$A_{4,4,1}$	7,225
$X_{13,37}$	57	$Y_{14,2}$	69	$A_{4,5,1}$	8,250
$X_{13,39}$	106	$Y_{15,2}$	20	$A_{5,2,1}$	8,250
$X_{14,37}$	161	$Y_{16,2}$	70	$A_{5,4,1}$	7,225
$X_{15,37}$	47	$Y_{17,5}$	133	$A_{5,5,1}$	8,250
$X_{16,37}$	163	$Y_{18,5}$	232	$A_{6,2,1}$	3,575
$X_{17,41}$	311	$Y_{19,5}$	110	$A_{6,4,1}$	3,131
$X_{18,41}$	541	$Y_{20,5}$	122	$A_{6,5,1}$	3,575
$X_{19,37}$	257	$Y_{21,5}$	146	$A_{7.2,1}$	4,675
$X_{20,37}$	284	$Y_{22,5}$	87	$A_{7.4,1}$	4,094
$X_{21,39}$	340	$Y_{23,5}$	132	$A_{7.5,1}$	4,675
$X_{22,35}$	171	$Y_{24,5}$	128	$A_{8.2,1}$	13,75
$X_{22,37}$	32	$Y_{25,5}$	134	$A_{8.4,1}$	12.04
$X_{23,35}$	307	$Y_{26,5}$	224	$A_{8.5,1}$	13,75
$X_{24,11}$	20	$Y_{27,5}$	143	$B_{2,3}$	4.050
$X_{24,28}$	279	$Y_{28,5}$	202	$B_{4,2}$	3.547
$X_{25,28}$	312	$Y_{29,5}$	110	$B_{5,3}$	4.050
$X_{26,35}$	522	$Y_{30,5}$	100	$E_{2,1}$	656,19
$X_{27,28}$	333	$Y_{31,2}$	10	$E_{3,2}$	1498,5
$X_{28,26}$	395	$Y_{32,2}$	50	$F_{3,1,1}$	14,235
$X_{28,28}$	75	$Y_{33,2}$	80	$F_{4,1,1}$	3,559
$X_{29,26}$	256	$Y_{34,5}$	95	$F_{5,1,1}$	3,559
$X_{30,26}$	233	$Y_{35,5}$	153	$F_{6,1,1}$	1,542
$X_{31,50}$	23	$Y_{36,2}$	71	$F_{7,1,1}$	2,017
$X_{32,26}$	116	$Y_{37,2}$	93	$F_{8,1,1}$	5,931
$X_{33,11}$	77	$Y_{37,5}$	110	$Fm_{3,1,29}$	80,666
$X_{33,25}$	109	$Y_{38,2}$	156	$Fm_{4,1,29}$	20,167
$X_{34,25}$	221	$Y_{39,2}$	84	$Fm_{5,1,29}$	20,167
$X_{35,25}$	357	$W_{11,4}$	379	$Fm_{6,1,29}$	8,739
$X_{36,11}$	165	$W_{25,2}$	686	$Fm_{7,1,29}$	11,428
$X_{37,50}$	473	$W_{26,5}$	1.000	$Fm_{8,1,29}$	33,611

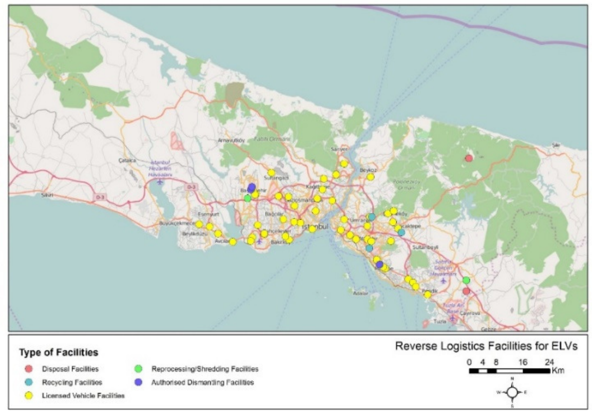

Figure 5. Locations of Authorized Dismantling Facilities and Reprocessing/Shredding Facilities Decided to Open

According to the optimal results, 9.744 of ELVs have been transferred from the ELV source points to the licensed vehicle collectors. All ELVs in licensed vehicle collectors have been transferred to authorized dismantling facilities with number 2, 4 and 5.7003 of ELVs have been transferred to the authorized dismantling facility numbered 5 from the ELV source points and licensed collection facilities. 12.235,576 tons of components and materials were transported to the recycling facility numbered 1 from authorized dismantling facilities.11,647 tons of hulk were transported from the authorized dismantling facilities numbered 2, 4 and 5 to the processing/shredding facilities numbered 2 and 3. 2.154,693 tons of ASR were transferred to disposal facilities numbered 1 and 2, from the 2 and 3reprocessing/shredding facilities.There is no flow of component or material from the reprocessing/shredding facilities to the recycling facilities.14,235 tons of plastic, 3,559 tons of tires, 3,559 tons of glass, 1,542 tons of batteries, 2,017 tons of fluids and 5,931 tons of other materials were transferred from the recycling facility numbered 1 to the disposal facility numbered 1. The locations of the authorized dismantling facilities and the reprocessing/shredding facilities, which are decided to be opened, are shown in Figure 5.

5.1 Sensitivity Analysis

In this section of the study, we conduct some analysis to determine effecting of some parameters on results.

i. Sensitivity to Number of Vehicles Deregistered from Traffic:

It is thought that there was an increase in the number of vehicles deregistered from traffic. How this increase will affect the number of authorized dismantling facilities and reprocessing/shredding facilities and value of objective function has been researched. As a result of the investigations made, the values in Table 6 were obtained.

The increase in the number of vehicles deregistered from traffic did not change the number of authorized dismantling facilities; but it increased the number of reprocessing/shredding facilities. In addition, the increase in the number of vehicles deregistered from the traffic increased the optimal value of the objective function. This is shown in Figure 6.

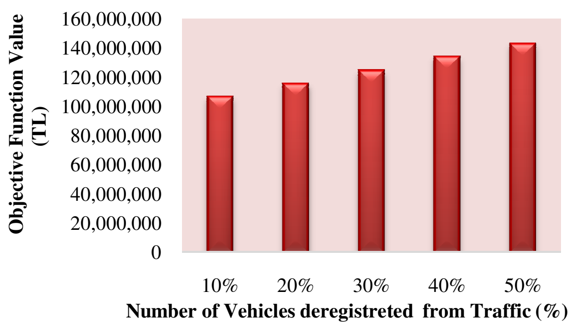

Figure 6. The Relationship Between Number of Vehicles Deregistered from Traffic and Objective Function

ii. Sensitivity to Number of ELV transported from ELV Source Point to Licensed Vehicle Collector:

It was assumed that the amount of ELV going from the ELV source point to the licensed vehicle collector changed. It has been researched how this change will affect the number of authorized dismantling facility and reprocessing/shredding facility and value of objective function. As a result of the investigations made, the values in Table 7 were obtained.

Change in the amount of ELV carried from the ELV source point to the licensed vehicle collector did not change the number of authorized dismantling facilities and reprocessing/shredding facilities but it increased the optimal value of objective function. This situation is illustrated in Figure 7.

6. CONCLUSION

The number of scrap vehicles has increased in connection with the rapid growth experienced in the Turkish automotive sector.Ensuring that ELVs are recycled under proper conditions or disposal with the right methods is crucial in protecting the environment.

Table 6. The Effect of Increase in Number of Vehicles deregistered from Traffic

Amount of Increase (%)	Authorized Dismantling Facilities	Reprocessing/Shredding Facilities	Objective Function Value
10%	L2,L3	K2,K3,K4,K5	106.117.217
20%	L2,L3	K2,K3,K4,K5	115.082.534
30%	L2,L3	K2,K3,K4,K5	124.047.889
40%	L2,L3	K1,K2,K3,K4,K5	133.638.267
50%	L2,L3	K1,K2,K3,K4,K5	142.603.661
100%	Integer Infeasible		

Table 7. The Effect of Change in the Number of ELVs in Licensed Vehicle Collector

Transported ELV Ratio Change from ELV Source Point to Licensed Vehicle Collector	**Authorized Dismantling Facilities**	**Reprocessing/Shredding Facilities**	**Objective Function Value**
0	L2,L3	K2,K4,K5	66.330.690
10%	L2,L3	K2,K4,K5	70.644.394
20%	L2,L3	K2,K4,K5	74.958.109
30%	L2,L3	K2,K4,K5	79.271.831
40%	L2,L3	K2,K4,K5	83.585.556
50%	L2,L3	K2,K4,K5	87.899.285
60%	L2,L3	K2,K4,K5	92.213.091
70%	L2,L3	K2,K4,K5	96.526.930
80%	L2,L3	K2,K4,K5	100.840.802
90%	L2,L3	K2,K4,K5	105.154.687
100%	L2,L3	K2,K4,K5	109.468.575

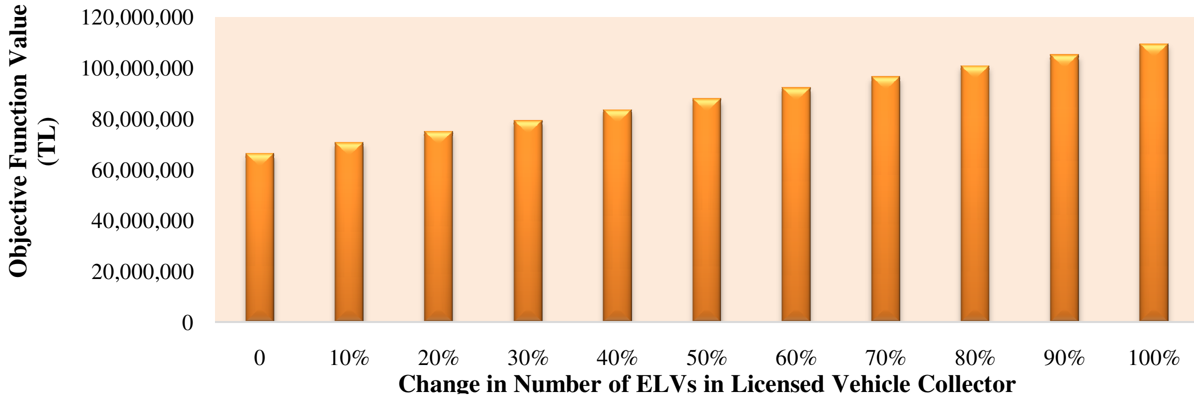

Figure 7. The Relationship Between the Number of ELVs and the Objective Function at the Licensed Vehicle Collectors

In this worka mixed integer programming model is developed to minimize the total system cost for ELVs recycling network design to determine the amount of material transported between the facilities, and to decide whether to open the shredding and dismantling facilities. The proposed model has been applied in the reverse logistic network design problem for ELVs in Istanbul. With this model, ELV and ELV material and components have been transported to the correct facilities and they have been solved by minimum cost by going through specific procedures.Two different sensitivity analyses were performed for the future changes and the behavior of the model was analyzed.

In the next studies, it can be developed stochastic or fuzzy mixed integer programming model which is considered some parameters (etc. quantity of ELV and transportation cost) on uncertain. In addition, close loop network can be designed to include manufacturers and suppliers as an actor in network.

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