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Design of reverse logistics network for waste tire incineration in cement factories

Çimento fabrikalarında atık lastik yakma için tersine lojistik ağı tasarımı

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Design of Reverse Logistics Network for Waste Tire Incineration in Cement Factories

Highlights

- ❖ *Reverse logistics*
- ❖ *End-of-life tires*
- ❖ *Waste tire incineration in cement plants*
- ❖ *Mixed integer linear programming*

Graphical Abstract

Model for this network considers transshipment plan of waste tires between the echelons of supply chain and routes used to gather them.

Aim

In this study, logistic network design of waste tires sent from collection points to these factories to minimize the costs involved is planned.

Design & Methodology

Model that deal with this system are expressed as mixed integer linear programming (MILP) problem.

Originality

In terms of the collection of waste tires, Turkey is divided into 8 regions and there are contractor firms that are authorized in each region. According to the information received from LASDER; approximately 30000 tons of waste tires was collected in North Central Anatolia region in 2017, and 20000 tonnes of these tires came from Ankara. Because of the great volume of the problem, study will be centered upon Ankara.

Findings

Total 20000 tons of waste tires gathered from accumulation points. 17400 tons of them burned in cement factories as a fuel. It is shown that in given environment optimal plan is with the 30 clusters.

Conclusion

High numbers of accumulation points of wastes can lead in confusions in collection plan and high costs. Thus multiple vehicle planning or clustering and routing methods has been applied. These waste tires are replaced with the fossil fuels that are used in cement factories so benefit of this process is not limited only with the proper disposal of waste tires. Another benefit gained from process is preservation of fossil fuels.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Çimento Fabrikalarında Atık Lastik Yakma için Tersine Lojistik Ağı Tasarımı

Araştırma Makalesi/Research Article

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ÖZ

Bu çalışma, kullanım ömrü dolmuş lastikler (ELT'ler) için kurtarma seçeneklerine odaklanmaktadır. ELT'ler için en uygun kurtarma seçeneklerinden biri, çimento fabrikalarında bunların yakılmasıdır. Türkiye'de son işleme tesisi olarak Çevre İzin ve Lisans Belgesi'ne sahip 49 entegre çimento fabrikası bulunmaktadır. ELT'lerin geri dönüşümlerinin çevreye getirdiği faydalarının yanı sıra, sürecin maliyet yönü de çok önemlidir. Bu çalışmada, toplama noktalarından bu fabrikalara gönderilen maliyetleri azaltmak için atık lastiklerin lojistik ağı tasarımı planlanmıştır. Atık lastik toplama noktası, yüklenici firmalar ve çimento fabrikaları olarak üç tedarik zinciri kademesi bulunmaktadır. Bu ağın modeli, tedarik zincirinin kademeleri ile bunları toplamak için kullanılan yollar arasındaki atık lastiklerin aktarma planını dikkate almaktadır. Bu sistemle ilgilenen model karma tamsayılı doğrusal programlama (MILP) problemi olarak ifade edilmiştir. Bir örnek olay incelemesi olarak model Ankara için verilerle doğrulanmıştır.

Anahtar Kelimeler: Ters lojistik, atık lastik yakma, çimento fabrikaları, MILP.

Design of Reverse Logistics Network for Waste Tire Incineration in Cement Factories

ABSTRACT

This study focuses on recovery options for end-of-life tires (ELTs). One of the most proper recovery options for ELTs is incineration of them in cement plants. There are 49 integrated cement factories which have Environmental Permit and License Certificate in Turkey as the final processing plant. Besides benefits of recovering ELTs to environment, cost aspect of process is crucial. In this study, logistic network design of waste tires sent from collection points to these factories to minimize the costs involved is planned. There are three echelons of supply chain as waste tires collection point, contractor firms and cement factories. Model for this network considers transshipment plan of waste tires between the echelons of supply chain and routes used to gather them. Model that deal with this system are expressed as mixed integer linear programming (MILP) problem. As a case study, model verified with data's for Ankara.

Keywords: Reverse logistics, waste tire incineration, cement factories, MILP.

1. INTRODUCTION

Consumption of natural resources increases proportional to the human population in the world and to the improvements in technology. After industrial revolution, depletion in natural resources became important as we started consuming more day by day. One of the most important result of this trend in consumption is increase in waste. To create awareness about harm of wastes, lots of organizations and agencies are founded. Greenpeace, World Wildlife Fund and Natural Resources Defense Council can be given as examples for these kinds of foundations. From here one can say that, wastes of consumed products are important as products itself. Like these environment friendly foundations, states and producers are trying to reduce waste and effects of them. For example, in Turkey regulations about waste management is stated in "Atık Yönetimi Yönetmeliği"

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(2015). All the aspects of waste management are tried to be covered in that law in order to reduce effects of wastes.

There are many types of wastes ranging from organic wastes to industrial wastes and from non-hazardous to hazardous wastes. According to report published by European Commission (2006) which is about best available techniques for waste treatments, it is stated that there are 940 techniques to deal with these wastes and it is also given that some other techniques may be excluded. However, in general, in solid waste management, these techniques can be grouped under three sub-topics which are reducing, reusing and recycling [1]. Reduce is referring to reducing the amount of waste from beginning which is production by optimizing amount of used raw material. Reuse is meaning reutilizing the waste of used product for example using empty glass bottle again for storing any kind of liquid. Recycle is resolving materials from the waste and making it to usable for production.

Waste tires are one of the industrial wastes. In today's world, having an automobile is becoming ordinary think day by day. Also, improvements in industries are increasing the number of transportation vehicles and also the number of tires that are being used and consequently increase in the amount of scrap tires. When one looks for the amount of scrap tires in world which is 19.3 million tons that is stated by Ostojic et al. [2] importance of recycling them is emerging. There are number of usage areas of waste tires from civil engineering purposes, which are listed by Ostojic et al. [2] and can be elaborated with examples like foundation for roads and railways and erosion barriers, to heat generation by burning them. In these areas, using them in cement factories is one of the most important ones. That is originating from the being alternative fuel property of waste tires. As cement factories mainly running with fossil fuels it is feasible to apply waste tires to them. Additionally, relatively lower cost of waste tires is making them attractive for cement producers.

As cost of waste tires is very low, a need for a network planning is arising. Additionally, source of these wastes are more separated, geographically, than other resources, they are most likely to end up in city garbage or in tyre shops or traders. These two aspects make transportation of waste tires between the echelons of supply chain vital. Generally, supply chain for waste tires is consisting of three echelons levels. First level can be said as tyre changers or traders for waste tires where they are gathered at first. Second one is plant that is dedicated for processing waste tires into desired form or inventorying them until a demand occur. Third level is cement factories where waste tires are used.

At the first part of study tires will be studied. In the second part, current situation of waste tires in Turkey will be investigated. Later, literature review is located. In this part, past studies and articles will be explained in briefly. Moreover, related models which are giving insights for required network planning will be examined. In the fourth part of study, methodology that is going to be used for solving problems of network will be given within the details. Finally, in the last part, methodology will be tested with application on a case and outputs of it will be interpreted.

2. TIRES

Tires are basically a part of land-based vehicles and used in cars, bicycles, buses and commercial or duty vehicles. Main objectives of tires in a vehicle is providing necessary grip for traction, supporting vehicle handling, carrying load of vehicle and absorbing shocks from road. Although they are used in different environments, their compositions constitute nearly same components. That components are mainly rubber, which are synthetic and natural, steel cord, bead and wire, carbon black and some chemicals [3].

Although tires are tried to be built last longer, that does not mean expected life of them is infinite. Like every

other industrial product, tires become dysfunctional or useless when they fill their expected life. At the end of their life wastes of them is creating an environmental issue that should be taken care of.

As mentioned before, carbon based materials have a high percentage it is possible directly burn them and use it in reactors that are suitable for it. Pipilikaki et al. stated that in general 88 percent of tires in mass is composition of carbon and oxygen which makes their burning process rapid and makes their calorific value high [4]. Because of these properties of waste tires they are substitutes for fossil fuels, as an example one ton of tire derived fuel can substitute 1.25 tons of coal. Deolalkar has mentioned about calorific values of alternative fuels in his book [5]. Table 1 given below shows the calorific values of different fuels.

Table 1. Calorific values of fuels and some alternative fuels (Deolalkar, 2016)

| Fuel | Low Heat Value (kcal/kg) | High Heat Value (kcal/kg) |
|-----------------------|--------------------------|---------------------------|
| Coal | 6600 | 6900 |
| Petroleum coke | 7100 | 7800 |
| Waste-derived fuel | 5400 | 6200 |
| Waste tires | 7500 | 7900 |
| Wood | 4700 | 4900 |
| Sawdust | 4700 | 5100 |
| Municipal solid waste | 3200 | 3600 |
| Oil | 9600 | 10000 |
| Waste oil | 5000 | 5200 |
| Plastics | 9000 | 5300 |
| Paper | 2900 | |
| Solvents | 6000 | |

We can see that calorific value of waste tires are higher than coal which means that it is possible to use waste tires instead of coal. To conclude, although waste tires are dysfunctional for cars, they can be used in other ways. As they are scrap, their prices are relatively lower than substituted material.

3. END OF LIFE TIRES CONCEPT

3.1. End of Life Tires Concept in World

Governments are concerned about waste tires because of environmental effects of it and possible health effects to people when stored improperly. Additionally, as waste tires are valuable assets because of the materials in it, it is possible to gain profit from them when the recycling business done correctly. In this position, where profit is possible for recycling firms and responsibility of governments or municipalities is existing, it is possible construct different modes for managing end-of-life tires.

European Tyre & Rubber Manufacturer's Association (ETRMA), which is an association that defends benefit of tyre and rubber manufacturing industries across Europe and other international levels, stated three different models that are being applied in Europe. First model is named as extended producer responsibility and it is including the producer of tire in the process of recycling fully or partially. Second model is referred as liberal system. In this system, free market conditions are valid for companies or firms that are dealing with end-of-life tires. This system is applied by 4 countries in Europe. Last model for managing waste tires is tax system. In this system, management of end-of-life tires (ELT) is done by governments. Its financial responsibility is left to producer by a tax and a portion of this tax passed on to the consumer. In Denmark and Croatia tax system is applied. In short, it can be said that nearly all of the European countries have a system for management of waste tires. Additionally, Uruburu et al. mentioned about end-of-life tire management system in Spain and shared statistics for the years between 2006 and 2010 [6]. It is stated that, among the energy recovery options for waste tires cement manufacturing area have the highest percent, which is more than 95 percent, with a remarkable difference with other areas.

In these systems, as mentioned before, waste tires can be reutilized in different ways. There are different options for reusing them which are ranging from retreading to incineration. To sum up, with the different usage areas of waste tires which have different effects on environment and which are varying in operational costs, usage percentages for distinct purposes can vary between countries. Also, that is dependent on countries' needs and governments are using different methods when dealing with them and have specific legislations about them.

3.2. End of Life Tires Concept in Turkey

Like the examples of applications for waste tire managements across world, Turkey have legislation about end of life tires. On 11.04.2007, tire manufacturers came together to establish Tire Industrialists' Association (LASDER) and took on the obligation to collect waste tires. In this context, a total of 19 facilities become entitled to receive recovery licenses from 2007 to 2012. At present, there are around 35-40 million tire production capacities in Turkey and all of the raw materials used in tire production are imported. The recovery / recycling of tires are very important in terms of economy and environment. ELTs operate in two basic areas: energy recovery and material recovery.

According to publishing by Ministry of Science, Industry and Technology of Turkey (2014), every year in Turkey about 200,000 tons of tire life has been ended. Many products can be obtained by recycling a tire. As a result of recovering 200,000 tons of end of life tire; about 146,000 tons of rubber granules and 38,000 tons of steel is being recovered.

ELT is considered as an alternative fuel to obtain energy, especially in the cement plant used, in lower sulfur

content and to obtain the same energy value. In Turkey, there are several recycling plants which can process ELTs by the Environmental Permit and Undergraduate Certificate from the Ministry of Environment and Urban Planning. Another important issue tire recycling management is the cement factory that is considered as customer or demand point. According to Turkish Cement Manufacturers' Association (TÇMB) report, the total number of entegreted cement factories in Turkey is 49 [7]. With a production of approximately 100 million tons, Turkey is the 5th biggest producer of cement in the world.

4. NETWORK DESIGN FOR ELT USAGE PROBLEM

To gain insights about related areas for designing a reverse logistic for waste tires necessary literature research is done. For beginning, because of the existence of flow of material between the nodes in supply chain, general models for transportation and models for supply chains is examined. Other crucial aspect of establishing a new facility is its location. To see how a decision about a facility's location is given, related works is researched. Additionally to these models and solution methods, there are new approaches to voluminous problems and vehicle routing problems. These approaches can be named as clustering algorithms. To consider solution methods with clustering algorithms in network problems, related works, which are about general clustering algorithms and their application areas, is searched. To clarify usage of end of life tires in cement factories, necessary research is done. Finally, past works about waste tire networks and waste tire supply chains is examined for getting info about considered aspects in waste tire recovery. Examples of the titles mentioned are given below.

Williams explained related models with the supply chain in his book [8]. Related models are profit maximizing model with multiple plant, transportation models with single product and a derivative of travelling salesman problem model. First one is dealing with the capacity allocation when operating more than one facility, second model is dealing with the assignments of transportation vehicles and the last model is for routing of transportations vehicles for multiple periods. Goetschalckx illustrated related models with a supply chain network [9]. They are single vehicle round trip routing models, vehicle routing models with time windows, some of the vehicle routing heuristics and multi echelon supply chain models. While these models applied to a wide variety in transportation and network models, voluminous problems may need other solution approaches because of computation time. One example of this kind of problems is multiple vehicle routing problem. In multiple vehicle routing problem there are a number of repositories, vehicles, and delivery locations and the problem is to optimize the routes of the vehicles. The Clarke and Wright savings algorithm is one of the most known heuristic for VRP. It was developed by Clarke and Wright and it applies to problems for which

the number of vehicles is not fixed (it is a decision variable), and it works equally well for both directed and undirected problems [10]. When two routes can feasibly be merged into a single route, a distance saving is generated.

While planning a network, facility location problems is an important issue. It is crucial to give an optimal decision about facility's location. Eiselt and Laporte illustrated main elements of Facility Location Problems as space where the facilities are to be located; service demand that are expressed by customers; interaction between customers and facilities; metrics to measure distances between customers and facilities; constraints to be satisfied [11]. Liu et al. introduce a location model that assigns online demands to the capacitated regional warehouses currently serving in store demands in a multi-channel supply chain [12]. Problems with covering constraints were defined in the 70's. The objective in this case is to locate facilities such that demand areas (clients) are covered. A demand area is said to be covered by a facility (server) if it is within a critical, pre-defined distance (time) from this facility. The simplest of these models seeks to find the minimum number of facilities (and their locations) such that all demand areas are covered by at least one facility.

To have information about one of the current trends in industrial engineering which is using clustering algorithms, required study have been done. These algorithms are used in very wide areas ranging from big data analysis, pattern recognition to social sciences. It can be said that these algorithms can be applied to any area which involves a data about many different points and requires a classification between them. Naalusamy et al. talked about using clustering algorithms in difficult and computationally voluminous environments [13]. One of the areas that clustering used is NP-hard models. Vehicle routing problems is one of such models. They applied clustering algorithms to multiple vehicle routing problem and multiple travelling salesman problem and showed that the efficiency of it. Jain and Dubes explained in their books about clustering algorithms. Jain mentioned about k-means clustering algorithm in his article [14]. He gives general information about clustering algorithms and the purpose of them while stating the advantages of k-means algorithm.

One of the areas of utilization for energy generation from waste tires is using them in cement factories. Cement factories have a burning process in the production of cement where most of the time coal is used. Advantages of using waste tires in cement factories have been examined by many researchers and engineers. Kop et al. conducted a research for a selection between the ELT management methods in current conditions [15]. They stated that incineration of waste tires in cement factories can be named as the most suitable method. Additionally, Deolalkar outlined advantages of using alternative fuels such as waste tires in cement plants [5]. The most significant aspects can be said as running on lower cost

for required burning process and making contribution to removal of waste tires from environment.

General problem about waste tires is a cost minimization problem and some of them have profit maximization as a second objective. First of all, Han et al. in their studies, they developed a linear model that is minimizing the cost of building recycling facilities, cost of transportation and cost of processing the waste tires [16]. They have aimed to obtain optimized flow assessments between the levels of reverse logistic supply chain. Sasikumar et al. constructed a mixed integer non-linear programming model that is maximizing the profit of multi echelon reverse logistic network which is constructed for returned products which are recycled or remanufactured [17]. Representation of network is given below in figure 1.

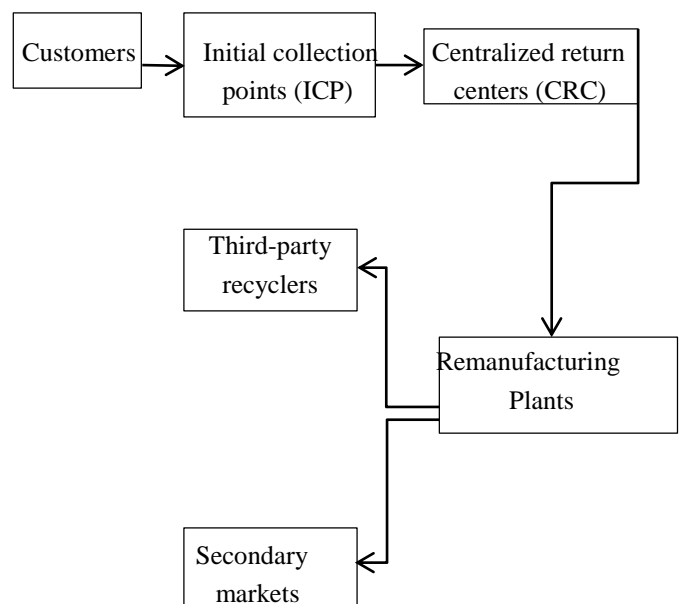


Figure 1. Representation of product recovery network (Sasikumar et al., 2010)

Their network is constructed for returned products which are recycled or remanufactured. The network is consisting many elements which are customers, initial collection points, centralized return centers, remanufacturing plants and third-party sellers and secondary markets which are end points for the returned product in the network. To sum up, in a reverse logistics network, it is possible encounter with many different aspects which are related parties to mentioned network. That is because of the fact that systematic approach is taken, which is a holistic approach rather than a reductive approach. Moreover, result of the taken approach may be useful for some of the parties or entire parties in said network. That is dependent on considered points while constructing model for network.

5. CASE STUDY

LASDER, an organization that founded by tire producers which have operations in Turkey, it is stated that

LASDER is gathering nearly 200000 tons of waste tires at Turkey. In order to manage this amount of waste tires a systematic approach should be taken. However, in current application for gathering of waste tires, LASDER is operating on daily decisions.

In terms of the collection of waste tires, Turkey is divided into 8 regions and there are contractor firms that are authorized in each region. According to the information received from LASDER; approximately 30000 tons of waste tires was collected in North Central Anatolia region in 2017, and 20000 tonnes of these tires came from Ankara. Because of the great volume of the problem, study will be centered upon Ankara. These waste tires needed to move cement factories via contractor firms. To elaborate supply chain of waste tires a representation of system is given in figure 2 below.

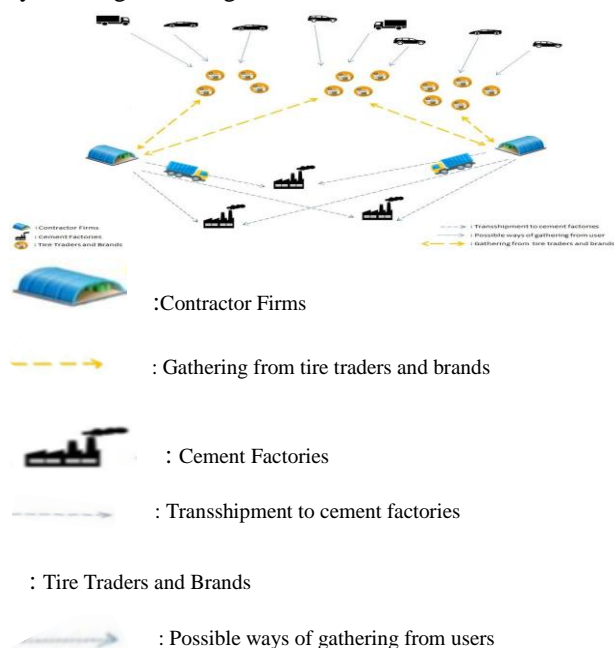


Figure 2. Representation of system of recycling of tires

In here, there are three echelons of supply chain. After customer done with their tires, waste of them are accumulated at tire shops. Blue facilities below tire shops are representing the contractor firms. Lastly, black facilities are representing the cement factories. Colored arrows are representing the flow of waste tires and shredded waste tires between echelons.

In current situation, in city Ankara amount of created waste tires is 1543425 tires in year of 2017. Although all of tires are not same with each other, an assumption states that 80 percent of generated amount is car tires and 20 percent of them is truck or bus tires. Additionally, average weight of car tires is 9 kg and average weight of truck tires is 45 kg. This amount of waste tires is accumulated at waste tire accumulation points which points needed to be visited at least weekly. These points

are tire shops or brands where city Ankara have 107 different tire shops or traders. Nearly all of the waste tires generated by consumers is end up at these accumulation points. Although amount of waste tires accumulated at these points are different, accumulation rate of waste tires is assumed to be uniform over the year.

Second level of supply chain is consisting of waste tires processing facilities. Contractor firms are connection between the sources of waste tire and cement factories. Their output is waste tires where they are not processed, and they are directed to factories. In Ankara, currently there are 3 other companies in this business.

Third level of supply chain is cement factories. These are the final points for waste tires. In Ankara there are 3 different cement factories that are allowed to use waste tires. Their quota for using waste tires are given in table 2 in units of tons.

Table 2. Limits for usage of waste tires in cement factories in tons

| Cement Factories | Limits |
|------------------|--------|
| 1 | 8200 |
| 2 | 5000 |
| 3 | 4200 |

To sum up, bringing waste tires to cement factories from the consumers of tires can lead to high costs if it is not done correctly. As in every reverse logistics, main cost aspect is the transportation cost which is 2 TL per kilometer for empty truck and additional 0.35 TL per ton. To manage flow between consumers and factories a systematic approach should be taken. Under these conditions, overall cost for this process should be minimized.

6. SOLUTION METHOD

Optimal solution to problem can be obtained by applying multiple vehicle routing problem models however it is not possible to get solution in a reasonable time because of the volume of the problem. So, it is needed to simplify problem or break into parts to solve it properly. To handle problem, a step by step solution method is applied. Method is beginning with clustering algorithm which is used for reducing the size of problem. After that, travelling salesman problem model applied to resulting clusters to get routes between accumulation points and contractor firms. Finally, a model is used to choose used routes by contractor firms and to determine to amount of waste tires that flows between contractor firms and cement factories. These models are programmed and implemented in GAMS (General Algebraic Modeling System) optimization package and solved using the

CPLEX solver. To elaborate steps sequencing of them is given below. Sequence of steps in method:

- Clustering accumulation points where number of clusters is 5k. Initial k is chosen to be 1.
- Obtaining distances for resulted clusters by using travelling salesman problem model.
- Solving network problem by using generated model for problem and recording their objective function values.
- Repeating steps until $k=11$.
- Choosing the number of clusters with best objective function value.
- Further searching to be sure about optimality which is repeating first three steps for the number of clusters with the best objective function value, n , between the interval $n+4$ and $n-4$.
- Choosing the optimal solution with best objective function value.

Clustering

Firstly, there is need for distinct and certain clusters because of the joint tenancy of accumulation points by contractor firms. To track amount gathered from accumulation points in an easy way clusters should be same for every other contractor firms. Jain and Dubes (1988) pointed out that use of sum of squared error method yields more compact clusters also mentioned about advantage of k-means which is an algorithm that is widely used and the most effective one among these algorithms. As objective of applying clustering algorithms is obtain compact and isolated clusters, k-means algorithm chosen to be applied.

K-means algorithm starts with a determined number of clusters which are not optimal. That is because of the evaluation of the clusters is dependent on the objective function value of network model. Secondly, cluster centroids are determined by algorithm's itself randomly. It is impossible to determine exact centroids before applying the algorithm so it starts with randomly generated centroids. It continues with assignment of points to the clusters according to their closeness to the cluster centroids. In every iteration, algorithm updates clusters centroids because as points are added to clusters centroids are changing. This repetitive process continues until there is no possible assignment of points to the clusters. As an example, clusters of first iteration is given below in figure 3.



Figure 3. Representation of clusters on map

Obtaining Route Distances

After clusters are obtained, it is needed to be settle routes from contractor firms. Because of the amounts at accumulation points are less than a full truck load which is 12 tons and these amounts are needed to be collected every week, it is logical to aggregate points to increase truck load per travel. There are several methods to get routes but to reach optimality in routes TSP model is used. Laporte examined solution approaches for travelling salesman problem and stated that formulation done by Miller, Tucker and Zemlin (MTZ) is an exact model to solve the problem [19]. MTZ model like other TSP models takes points as sets for model which are i and j and have one parameter which is cost associated with distance between points. Decision variables and parameters that are used in model is given below with their definitions.

$X(i,j)$: Equals to 1 if a truck or person goes to j from i .

$U(i)$: Positive integer variable that states order of point i in tour.

$D(i,j)$: Distance or cost parameter of using arc between i and j .

MTZ model is given below beginning with objective and constraints.

$$\text{Min } z = \sum_i \sum_j d(i,j) * x(i,j) \quad (1)$$

$$\sum_j x(i,j) = 1 \quad \forall i \quad \sum_i x(i,j) = 1 \quad \forall j \quad (2),(3)$$

$$U(1) = 1 \quad (4)$$

$$U(i) \geq 2 \quad \forall i, i \neq 1 \quad (5)$$

$$U(i) \leq n \quad \forall i, i \neq 1 \quad (6)$$

$$U(i) - U(j) + 1 \leq n * (1 - x(i,j)) \quad \forall i, \forall j, i \neq 1, j \neq 1 \quad (7)$$

In here, objective is getting route for given points with the least cost. First two constraints are stating that every point should be visited exactly once. Following constraints are needed for subtour elimination third constraint is necessary for arranging beginning point of route. Last three constraints ensure that there is no subtour in optimal solution by ranking given points between 2 and n which is total number of units in sets i and j . Last constraint is needed for determine their exact sequence number in route.

All accumulation points and contractor firms are entered as sets according to their clusters. All of the clusters routed by using MTZ model for every other contractor firms. Purpose of doing this is getting the distances of routes while collecting waste tires. These distances will be used in following steps as parameters. As an example, routes obtained for contractor firm 'A' by applying MTZ model for five clusters are given below in table 3 and

resulted length of routes for each contractor firm is given in table 4.

Table 3. Routes for clusters from contractor firm A and their lengths in kilometer

| Cluster | Route | Length of Route |
|---------|---|-----------------|
| 1 | A-75-36-11-76-10-35-3-73-95-106-33-64-32-67-14-102-37-79-2-12-103-40-48-38-13-61-62-70-69-39-41-1-105-A | 32.00 |
| 2 | A-104-84-87-5-29-31-80-94-30-27-63-34-86-28-26-24-25-85-A | 51.65 |
| 3 | A-42-43-45-90-81-17-4-18-55-68-47-89-97-98-6-77-91-82-19-56-65-50-83-78-20-107-16-15-60-59-44-A | 32.40 |
| 4 | A-71-46-21-9-7-52-57-8-22-66-58-72-101-100-23-54-49-88-99-92-74-A | 47.18 |
| 5 | A-51-96-53-93-A | 45.83 |

Table 4. Lengths of routes from contractor firms to clusters in kilometers

| Contractor Firms/Clusters | 1 | 2 | 3 | 4 | 5 |
|---------------------------|-------|-------|-------|-------|-------|
| A | 32.00 | 51.65 | 32.40 | 47.18 | 45.83 |
| B | 56.36 | 50.31 | 61.13 | 55.40 | 18.52 |
| C | 48.01 | 57.65 | 39.61 | 38.17 | 32.39 |

Network Model

To begin with, network models in given literature have been examined and a proper model for problem have been constructed. To construct a model a few assumptions have been made. Firstly, parameters which are about capacity, amounts, weights and prices do not change over a year. Distribution of waste tires among accumulation points does not change over time and it accumulates evenly with time that is to say that accumulation per time is constant. About amounts, rate for type between car tires and truck or bus tires is constant over year and average weights for them do not change. This proportion is assumed to be same for every accumulation point. Tire amounts at accumulation points are converted to weight, in tons, from numbers. It is done by using proportion between car tires and truck or bus tires and their average weights of them. In short, a tire is assumed to be 16.2 kg which is weighted average for different tire types.

At second level of supply chain, contractor firms are assumed to be limitless in capacity. Truck numbers contractor firms have assumed to be enough for any plan. All of the trucks that are used in network assumed to be same. Also there is no partitioning in routes in case of any route have less than full load of truck and it is assumed that there is no process about waste tires such as shredding or breaking.

At cement factories, they are assumed to be indifferent between waste tire types. Also, their demands are assumed to be nonrestricted by time. To clarify, cement

factories accept waste tires whenever contractor firms send them.

According to problem given, model needs three different sets which are r for clusters, i for contractor firms and j for cement factories. Parameters that are used in model is listed below with their explanations.

- Rdist(i,r): Length of route for cluster r and contractor firm i.
- Fdist(i,j): Distance between contractor firm i and cement factory j.
- Dem(j): Demand of factory j.
- Ava(r): Available amount of waste tires at cluster r.
- Tvarcost: Variable cost for a ton of waste tire per kilometer which is 0.35 TL.
- Tdistcost: Fixed cost for travelling with truck which is 2 TL per kilometer.
- Truckcap: Capacity of a truck which is 12 tons.

To decide amounts of waste tires transferred between the echelons of supply chain different decision variables is used which are listed below.

- Cx(i,r): Amount of waste tires collected from cluster r by contractor firm i.
- Fx(i,j): Amount of waste tires sent to cement factory j from contractor firm i.
- NumofTravelRoute(i,r): Integer variable for number of travels to cluster r from contractor firm i.
- NumberofTravelFactory(i,j): Integer variable for number of travels to cement factory j from contractor firm i.

As problem requires the minimization of transshipment cost of waste tires within the supply chain, by help of given and obtained parameter and constituted decision variables, objective function for model can be written as given below.

$$\text{Min } z = \sum_i \sum_r Cx(i, r) * Tvarcost * Rdist(i, r) + \sum_i \sum_j Fx(i, j) * Tvarcost * Fdist(i, j) + \sum_i \sum_r \text{NumofTravelRoute}(i, r) * Tdistcost * Rdist(i, r) + \sum_i \sum_j \text{NumofTravelFactory}(i, j) * Tdistcost * Fdist(i, j) \tag{8}$$

In objective function, variable costs that arises from transferring amounts of waste tires between the echelons of supply chain is expressed distinctively in first two summations. Last two summation is the fixed part of the total cost.

As problem states there are some requirements and limitations in given supply chain and because of the

existence of natural dependencies model requires some set of constraints which are listed below.

$$\sum_i Fx(i, j) \geq Dem(j) \quad \forall j \quad (9)$$

$$\sum_i Cx(i, r) \leq Ava(r) \quad \forall r \quad (10)$$

$$\sum_j Fx(i, j) \leq \sum_r Cx(i, r) \quad \forall i \quad (11)$$

$$Cx(i, r) \leq NumofTravelRoute(i, r) * Truckcap \quad \forall i, \forall r \quad (12)$$

$$Fx(i, j) \leq NumofTravelFactory(i, j) * Truckcap \quad \forall i, \forall j \quad (13)$$

$$\sum_i \sum_r Cx(i, r) \geq \sum_r Ava(r) * 0,8$$

$$\sum_i NumofTravelRoute(i, r) \geq 52 \quad \forall r \quad (14), (15)$$

In problem that is stated LASDER is responsible from a percent of waste tires which is 80 percent. That means gathered amount by contractor firms should be greater than 80 percent of the total waste tires. All the points should receive service as much as possible. Setting number of travels to a route from contractor firms greater or equal to 52 means that there should be a truck travelling to that cluster every week. Finally, third step of the process is applying model to the problem. An illustration of outputs of model is given below in following tables for first iteration which is with 5 clusters. Optimal solution with 5 clusters gives the objective function value as 421630.70 TL.

Iterations

After founded first objective function value to be sure from optimality, broad search for it should be done between the arrival where cluster numbers is ranging between 5 and 55. As an upper-bound for cluster numbers 55 is chosen because it is nearly half of the total numbers of points. As a conclusion graph given below in figure 4 is formed.

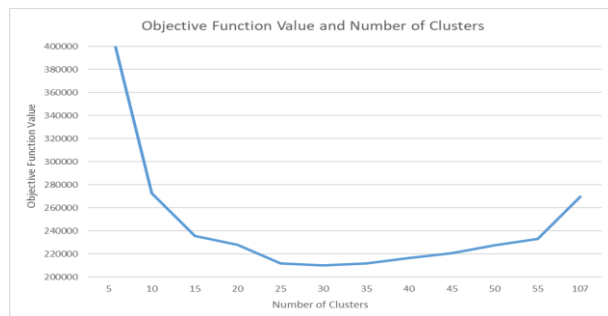


Figure 4. Objective function values at different number of clusters in TL

As it can be seen from the graph, increasing number of clusters dramatically reduces the objective function value at the low values of k. Additionally, graph is in u shape. This situation concludes that although high numbers for clusters is likely to have less objective function value than the one without clusters. Finally, in the graph, line

is nearly horizontal at the levels 25,30 and 35. As these three points have the lowest values in given interval optimal solution is most likely to be in this interval.

For clarification, within these three cluster numbers 30 have the lowest objective function value with 209904.13 TL. Other two cluster numbers, 25 and 35, have nearly same objective function value which are 211955.80 TL and 211986.86 TL, respectively. To conclude, in first iterations which are made with multiplies of 5 from 5 to 55, best objective function value is obtained with number of clusters 30. So, that makes second interval for number of clusters between 25 and 35 which can be said to be proper for further search for optimal solution according graph for first iterations. As the order of solution approaches suggests the interval as between 25 and 35, formed graph for that interval is given below in figure 5.

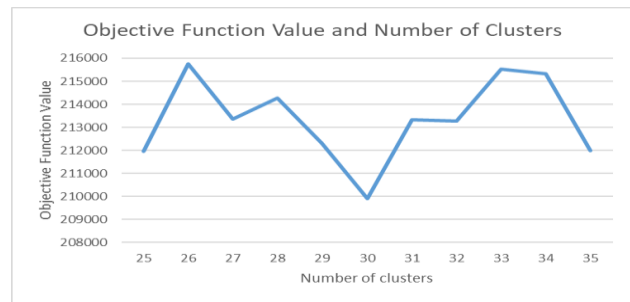


Figure 5. Objective function values for given number of clusters in TL

From graph, it can be seen that there are local optimum points. These points can be seen clearly in 27 and 32 which are have better objective function values at the intervals +1 and -1. Also this can be same for the 25 and 35. Although there is possibility for stuck in a local optimum by looking in figure 7.5, but, from the previous graph, finding lower values than these values apart from this interval is highly unlikely. As a result of this graph number of clusters that have the best objective function value is unchanged. So, the solution with 30 clusters can be regarded as global optimum solution.

Plan of the collection waste tires from accumulation points and transshipments of them to cement factories from contractor firms should be done according to result

with 30 clusters. The result of the network model is given in tables 5,6,7 and 8.

Table 5. Amount of waste tires collected from cluster r by contractor firm i in tons

| Cx(i,r) | A | B | C |
|---------|----------|--------|----------|
| 1 | 668.66 | | |
| 2 | | 252.72 | |
| 3 | 3,336.00 | | |
| 4 | | | 616.45 |
| 5 | | | |
| 6 | 573.89 | | 1,389.96 |
| 7 | | 447.53 | |
| 8 | 624.00 | | |
| 9 | | 242.19 | |
| 10 | 215.87 | | |
| 11 | | | 168.48 |
| 12 | | | 452.79 |
| 13 | 1,104.00 | | |
| 14 | | | |
| 15 | 624.00 | | |
| 16 | 624.00 | | |
| 17 | | 624.00 | 210.60 |
| 18 | | | |
| 19 | | | 689.72 |
| 20 | 2,184.00 | | |
| 21 | | | 1,260.00 |
| 22 | | 267.33 | |
| 23 | | 452.79 | |
| 24 | | 505.44 | |
| 25 | 410.67 | | |
| 26 | | | |
| 27 | 1,248.00 | | |
| 28 | 184.28 | | |
| 29 | 1.46 | | |
| 30 | | 624.00 | |

Table 6. Number of travels to cluster r from contractor firm i

| NumofTravelRoute(i,r) | A | B | C |
|-----------------------|-----|----|-----|
| 1 | 56 | | |
| 2 | | 52 | |
| 3 | 278 | | |
| 4 | | | 52 |
| 5 | 52 | | |
| 6 | | | 116 |
| 7 | | 52 | |
| 8 | 52 | | |
| 9 | | 52 | |
| 10 | 52 | | |
| 11 | | | 52 |
| 12 | | | 52 |
| 13 | 92 | | |
| 14 | 52 | | |
| 15 | 52 | | |
| 16 | 52 | | |
| 17 | | | 52 |
| 18 | | 52 | |
| 19 | | | 58 |
| 20 | 182 | | |
| 21 | | | 105 |
| 22 | | 52 | |
| 23 | | 52 | |
| 24 | | 52 | |
| 25 | 52 | | |
| 26 | 52 | | |
| 27 | 104 | | |
| 28 | 52 | | |
| 29 | 52 | | |
| 30 | | 52 | |

Table 7. Amount of waste tires sent to cement factory j by contractor firm i in tons

| Fx(i,j) | 1 | 2 | 3 |
|---------|----------|----------|----------|
| A | 8,200.00 | | 996.00 |
| B | | 212.00 | 3,204.00 |
| C | | 4,788.00 | |

Table 8. Number of travels to cement factory j by contractor firm i

| NumofTravelFactory(i,j) | 1 | 2 | 3 |
|-------------------------|-----|-----|-----|
| A | 684 | | 83 |
| B | | 18 | 267 |
| C | | 399 | |

With this clusters and given solution has the objective function value 209904.13 TL. In model, binding constraint which drives waste tires accumulation points to contractor firms is the percentage limit on LASDER. As a result of this, total gathered amount of waste tires from accumulation points is 20000 tons. That shows it is possible to increase utilization of waste tires in other cement factories.

Additionally, in the network model, fill rate of the trucks cannot be taken as a performance measure which is 86.91 percent at overall. That is because of the assumption which states distribution of waste tires at accumulation points over year is constant. However, this percentage can be considered as low but this percentage is dependent on the rate between fixed and variable parts of the transportation cost. If one checks for the number of travels to clusters from contractor firms, it can be seen that there are many 52s which is meaning that most of them are sent because of the obligation. Any relaxation in related obligation may result in a better situation for fill rate of trucks and also for objective function value. Also, it is proper to add that, network model does not consider capacity of the contractor firms.

That causes the model to be free while assigning contractor firms to clusters and cement factories. So, model simply assigning the closest ones to contractor firms. However, introducing any limitation on contractor firms about waste tire amounts can lead to increase in cost. Moreover, when this solution is compared with the current situation, solution with 30 clusters objective function is less than the current situation which is the one without clusters more than 50000 TL. As this is the only cost of the transshipment of the waste tires to cement factories from accumulation points, it is also directly proportional to the CO2 emission, so it is proper to say that this solution also beneficial for the environment. To sum up, although difference in objective function values at the flattest part of the graph obtained from the multiplies of 5 is small, difference between the optimal and the current situation is considerable.

7. CONCLUSION

As transportation is a part of life, waste tires can be regarded as a daily waste. However, waste tires are distinct from other daily wastes because of the reutilization opportunities of them. Also, it is proven that excessive amounts of waste tires can be harmful to environment. Thus, proper disposal of waste tires is important and between the methods for waste tires, burning them in cement factories is one of the most proper methods. In Turkey, LASDER is responsible from the huge part of the waste tires.

In a reverse logistics system not only the disposal methods but also the network model can result in a remarkable difference. However, in a reverse logistics system accumulation points of wastes may be dispersed from each other. High numbers of accumulation points of wastes can lead in confusions in collection plan and high costs. Thus applying multiple vehicle planning or clustering and routing methods can be beneficial. Ankara is studied as a case study with real accumulation points. It is shown that it is critical to choose the correct of clusters because an incorrect decision about number of clusters can result in higher costs than the working without clusters. Additionally, as the given network model considers only transportation costs in reverse logistics system for waste tires it is directly proportional with the CO₂ emission of trucks.

Total 20000 tons of waste tires gathered from accumulation points. 17400 tons of them burned in cement factories as a fuel. It is shown that in given environment optimal plan is with the 30 clusters. Additionally, these waste tires are replaced with the fossil fuels that are used in cement factories so benefit of this process is not limited only with the proper disposal of waste tires. Another benefit gained from process is preservation of fossil fuels.

Another aspect in this process is left amount of waste tires at accumulation points. However, waste tires are not only used in cement factories and they are also used in different sectors such as civil engineering purposes or used in recycling plants. As usage of waste tires in cement factories is studied, these aspects are not considered in model. Left amounts of waste tires may be reutilized in these sectors.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Müjde EROL GENEVOIS: Performed the experiments and analyse the results. Wrote the manuscript.

Merva DİNÇ: Performed the experiments and analyse the results. Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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