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Research Article

Waste collection and transport optimization in accordance with zero waste principles of Karaman province in Türkiye

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ABSTRACT

The zero waste approach introduces a novel perspective on waste management, allowing for the categorization of waste at its origin. This enables each identified waste group to be assessed and optimized individually. One of these optimization studies focuses on the optimization of waste collection and transportation. The placement and number of containers, as well as the collection routes of vehicles, are crucial for optimizing these processes. In this study, the number of containers placed in Karaman, their placement, the distance between the containers, and the vehicle route optimization were analyzed. The results show that the current number of containers is not used efficiently, with an average distance of only 33 meters between them. Moreover, optimizing routes in five pilot areas resulted in an average efficiency gain of 32%, which saved 17 kilometers, 50 minutes, and 8 liters of fuel per route. Based on these findings, a 32% improvement is anticipated not only in economic and time efficiency but also in reducing the carbon footprint during the collection and transportation stages.

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INTRODUCTION

The amount of waste produced globally is increasing due to rapid population growth, industrialization, economic growth aspirations, the desire for a luxurious lifestyle, and technological advancements across various sectors. This rise in waste generation has necessitated the adoption of zero waste principles, making it essential to manage waste production and consumption effectively. Direct disposal of waste without any treatment, neglecting recycling, recovery, and optimization processes, creates significant resource problems in terms of both energy and raw materials [1–3].

In recent years, significant advancements have been made in the field of waste management in our country. To promote the zero waste philosophy, the Ministry of Environment, Urbanization, and Climate Change (MoEU) encourages people to consume only what they need, reduce their waste, and separate waste at the source. Detailed studies have been conducted to ensure the collection and recycling of waste separated at the source. On September 25, 2017, the "Zero Waste Project" was launched in the MoEU service building. This project aims to create awareness and provide a roadmap, involving citizens in waste management through public institutions, organizations, hospitals, uni-

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versities, schools, airports, shopping malls, and households. The “Zero Waste Project” aims to prevent wastefulness and foster both corporate and individual responsibility [3, 4].

Conceptually, integrated solid waste management (ISWM) can be defined as a systematic and scientific discipline that encompasses the minimization, collection, transportation, processing, and final disposal of all waste types with a holistic perspective. ISWM considers factors such as the supply and demand balances of the region’s population, production and consumption habits, economic values, engineering solutions, protection of natural resources, aesthetic concerns, environmental and human health, and the preservation of natural assets like flora and fauna [5, 6]. This integrated approach ensures that all aspects of waste management are addressed, providing a comprehensive and sustainable solution [7].

Effective planning of waste management requires addressing various regional issues, including geography, physical elements, urban settlement patterns, building conditions, road conditions, livelihood, income levels, heating systems, and cultural habits. Understanding these factors helps in creating a tailored waste management plan that meets the specific needs of the region. Additionally, citizen support is crucial to reducing environmental impacts to near-zero levels with minimum cost and maximum benefit. Understanding the situation and expectations of the local population is vital for gaining their support. Projects and systems that lack citizen support are unlikely to be sustainable [8, 9].

Another critical aspect of integrated waste management is the selection and use of appropriate tools and equipment by local governments or private organizations. In the accumulation, collection, and transportation of waste, it is important to choose equipment and vehicles that are suitable for current technological standards and to evaluate them using technological capabilities. Well-planned selection, placement, and transportation of tools and materials can lead to significant savings in fuel, personnel, and equipment costs, while also reducing carbon emissions [10, 11].

In waste collection and transportation, various factors play a crucial role, including the structure and capacity of the containers, their placement, settlement frequency, the number of people per container, the condition of transport vehicles, the compression status and factor of vehicles, the distance of the disposal or recovery facility from the collection point, and the routing process. On average, 28 liters of fuel are consumed in an 8-hour operation depending on these factors. Additionally, the cost of collection and transportation ranges from 30$ to 70$ per ton of waste, making up 65–80% of total waste management costs. This highlights the importance of efficiently planning the collection and transportation systems to ensure sustainability [7, 12].

Another issue in integrated waste management is the collection and transportation of waste, which is the only point that individuals witness and experience directly in front of them. Dissatisfaction in these observations may lead to a decrease in the belief in waste management and zero waste by confronting the waste management and local administration with the perception of failure. Therefore, the integrated waste management system must be planned correctly and this plan must be strictly followed [6, 13–16].

This research aims to evaluate container locations and conduct an optimization study for waste collection and transportation systems in accordance with zero waste principles. By analyzing the current waste management practices in Karaman and optimizing the placement and routing of containers, this study seeks to enhance efficiency, reduce costs, and minimize the environmental impact of waste management processes.

MATERIALS AND METHODS

Current Situation of Karaman Province

Urban solid wastes in Karaman province are defined as wastes within the adjacent areas of Karaman Municipality and are collected by the Karaman Municipality Cleaning Affairs Directorate. The wastes of the district municipalities, those collected by the Special Provincial Administration, and the industrial wastes are not included in the urban solid wastes. Data on total urban solid waste, the number of containers, and location information of placed containers were obtained from the Cleaning Department of Karaman Municipality. Additionally, information on the types and numbers of vehicles involved in waste collection, waste collection route details, the number of containers on each route, vehicle tracking system data, current waste management practices, and other equipment details were also gathered.

Information on the amount of collected waste, the number of recycling containers placed, and the number of indoor boxes placed was obtained from Yunus Emre Cultural Foundation Economic Enterprise, which has a collection and separation facility license and an agreement with Karaman Municipality.

Information on the population of Karaman and the population of the neighborhoods was obtained from the official web page of the Karaman Governorship Provincial Directorate of Population and Citizenship.

The fuel consumption during the 8-hour operation of the compression vehicles used in the collection and transportation operations is taken as 28 liters [12].

Collection and Transport Optimization

The optimization process and maps of the vehicles used in the waste collection and transportation processes in Karaman were created using the ArcMap 10.5 program.

Finding Existing One-Day Routes of Collection Vehicles

The current route information reflects the daily movements of the Karaman Municipality Cleaning Affairs Directorate collection vehicles in the pilot areas. Coordinate data obtained from vehicle tracking systems of vehicles collecting in pilot areas was used. The coordinates received were transferred to the ArcMap 10.5 program. After the path

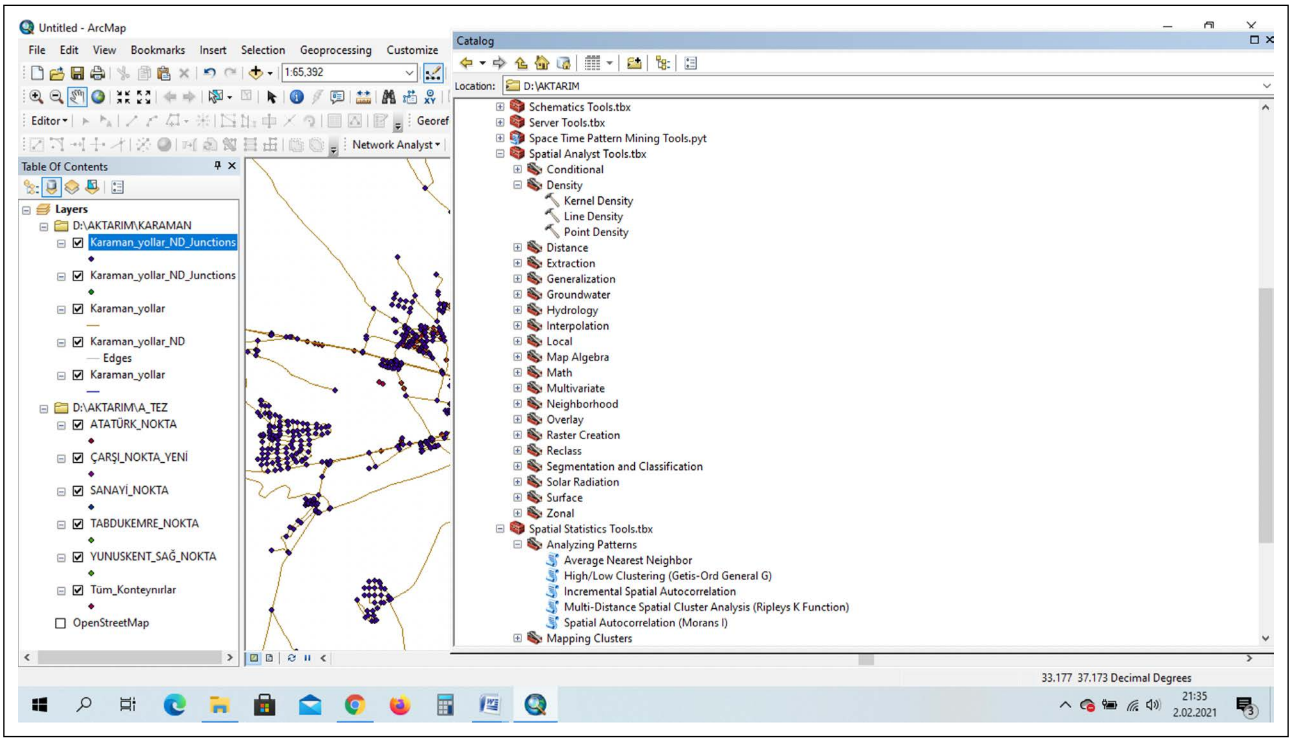

Figure 1. View of the density map rendering in ArcMap 10.5.

information was downloaded using OpenStreetMap, it was converted into a format that can be used in the ArcMap 10.5 program and roads were created. After creating the path and point data, routing was performed in the ArcMap 10.5 program with the Network Analyst tool to follow the sequential points (Fig. 1). Existing route drawings start with the movement of collection vehicles from the garage and end with their arrival at the disposal site. The distance from the disposal site to the garage is 7.7 km, and an average of 22 minutes is spent.

Container Data and Waste Density Map

The coordinates of the container locations were obtained from the Karaman Municipality Cleaning Affairs Directorate. These coordinates were input in the ArcMap 10.5 program according to the collection regions. By processing the road data using OpenStreetMap and the points, the container settlement map in Karaman and the container settlement status map in the pilot regions were obtained. Waste density maps were created using the Kernel Density toolbar in the Spatial Analyst Tool of the ArcMap 10.5 program by using the container point data and the container volume (800 L) in Karaman and in the pilot regions. The average nearest neighbor summary, showing the average distances between containers and their distances relative to the collection area, was obtained using the Average Nearest Neighbor toolbar in the spatial statistics tools of the ArcMap 10.5 program (Fig. 1).

Optimization of the Vehicle Routes

Route optimization was carried out considering the container layout in the existing 5 pilot regions, with the starting point being the Garage of the Cleaning Works Department and the ending point being the sanitary landfill. The Network Analyst module of the ArcMap 10.5 software was used for solid waste collection and optimum route determination. Working with the same logic as the smallest spanning tree method, this software enumerates the obtained solid waste coordinates on the road data by calculating the shortest distances between them and gives the optimum route between these points (Fig. 2) [15, 17–19].

RESULTS AND DISCUSSION

Current Situation of Karaman

The population for which waste collection service is provided by Karaman Municipality is 161,946 people. There are 63 neighborhoods in the center of Karaman. An average of 179,013 kg of waste is collected per day by Karaman Municipality. The amount of waste per capita in Karaman is 1.15 kg.

There are 4,750 containers placed on the site for the collection of urban solid waste (garbage collection). The volumes of the containers are 770 L, and there are 35 persons per container. The average waste volume per container is 0.25 m^3. The container utilization factor, which is the average occupancy rate when the containers are emptied, is 33%.

Urban solid wastes are collected by Karaman Municipality Cleaning Affairs Directorate with 9–13 m^3, 2–8 m^3, and 2–7 m^3 compression vehicles and disposed of in the sanitary landfill. No other process is applied for these wastes before disposal.

Detailed insights into the handling of oversized waste items, used cooking oils, and debris from building activities remain elusive. Information regarding hazardous waste materials, discarded mineral oils, depleted batteries, and out-

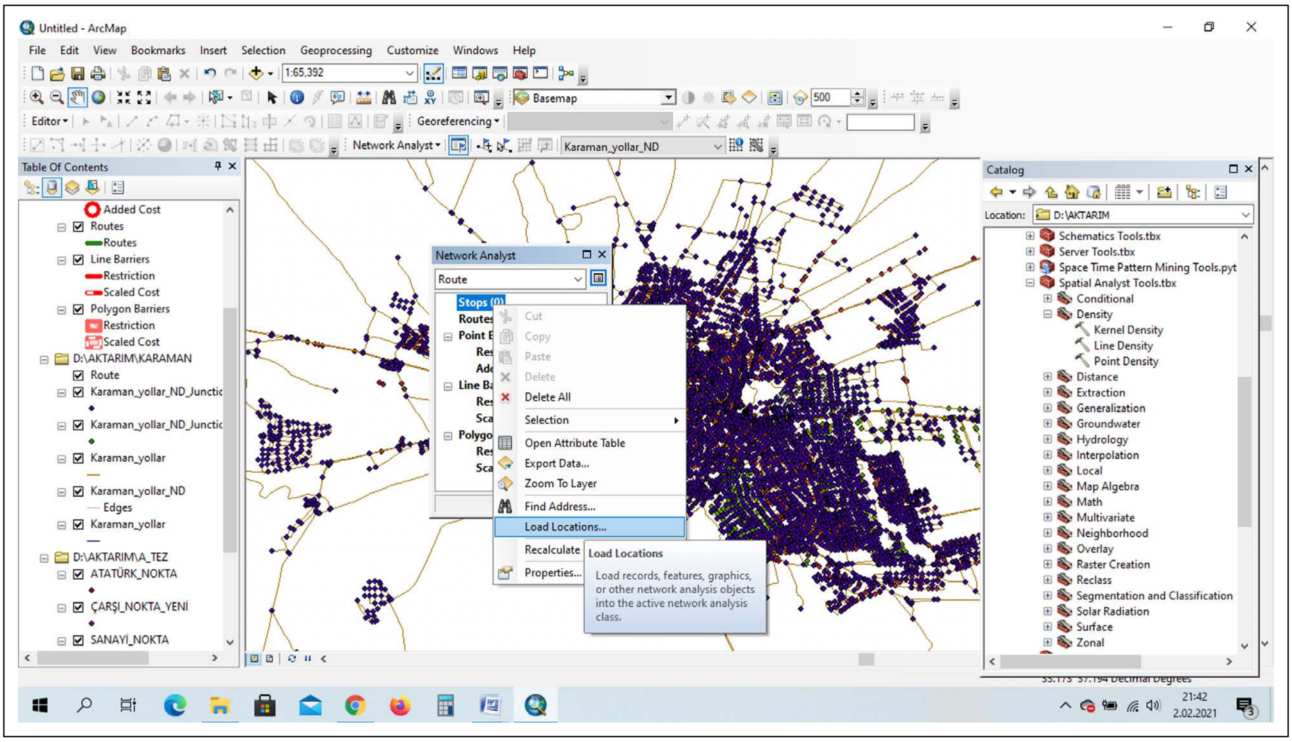

Figure 2. Network analyst data load view.

Table 1. Number of equipment installed and usage rates

Information of equipment placed in Karaman			
Total population (person)		**161946**	
Number of containers (pcs)	4750	Number of recycling containers	433
Container volume (m³)	0.77	Recycling container volume (m³)	2
Daily waste amount (kg/day)	179013	Number of indoor boxes	5950
Daily waste volume (m³/day)	1194	Waste retrieval center (7 compartments)	20
Karaman average waste density (kg/m³)	150	Daily amount of recyclable waste (kg/day)	63704
Number of people per container (person)	35	Daily recyclable waste volume (m3/day)	1118
Amount of waste per container (kg/day)	38	Karaman average recyclable waste density (kg/m³)	57
Waste volume per container (m³/day)	0.25	Number of persons per recycling container (person)	375
Container utilization factor	0,33	Amount of waste per recycling container (kg/day)	148
Number of containers required (piece)	2215	The volume of waste per recycling container (m³/day)	2,58
Average vehicle speed	18 km/h	Recycling container utilization factor	1,29
Compost unit	7 adet	Number of recycling containers required (pieces)	799
		Monthly amount of collected packaging waste (kg/month)	300000

dated tires is derived from industrial reports submitted to the Karaman Environmental and Urban Planning Authority. Additionally, the data on medical waste, as provided by this authority, is based on submissions from healthcare establishments in Karaman.

Packaging waste data can be divided in two ways: the first includes the packaging waste collected from industry and industrial organizations throughout Karaman, and the second includes the packaging waste information collected only from Karaman within the scope of the separation at source project. There are 433 recycling bins placed in Karaman by the licensed company. In addition, there are 5,950 indoor boxes distributed to households and workplaces. The volume of recycling containers is 2 m³ on average, and the number of people per container is 375. Considering the recyclable waste potential and the assumption that recycling containers are collected every day, the waste volume per container is 2.58 m³, and the container utilization factor is calculated to be 129%. In Karaman, the segregation processes for recycling yield an average daily collection of 10,380 kilograms of recyclable materials by authorized collection and sorting centers. The packaging waste gathered by the certified facility in Karaman accounts for 5.6% of the total

Table 2. Information on the amount of recyclable waste and equipment collected separately at source

Waste information collected separately at the source	
The amount of recyclable waste collected daily (kg/day)	10000
The volume of recyclable waste collected daily (m^3/day)	176
Amount of waste per recycling container (kg)	24
The volume of waste per recycling container (m^3)	0,41
Recycling container utilization factor	0,20

solid waste produced. Tables 1 and 2 provide a comprehensive breakdown of the waste types produced in Karaman.

Collection and Transport Optimization

Container Layout and Waste Density Map

Container density, container layout maps, and average distances of containers to each other were calculated by means of the ArcMap program within the framework of container coordinates obtained from Karaman Municipality Cleaning Affairs Directorate. In this framework, the average distance between the containers placed in Karaman is 33 meters, while the expected average distance is calculated to be 72 meters. The average distance between containers at the Atatürk location is 86 meters, with an expected average distance of 228 meters. The average distance between the containers at the Çarşı location is calculated as 73 meters, with an expected average distance of 132 meters. For the industrial site, the average distance between containers is 52 meters, with an expected average distance of 104 meters. For Tabduk Emre location, the average distance between containers is 58 meters, with an expected average distance of 146 meters. For Yunus Kent right location, the average distance between containers is calculated as 42 meters, with an expected average distance of 146 meters.

Finding Existing One-Day Routes of Collection Vehicles

The current route information reflects the daily movements of the Karaman Municipality Cleaning Affairs Directorate collection vehicles in the pilot areas. Coordinate data obtained from vehicle tracking systems of vehicles collecting in pilot areas was used. The coordinates received were transferred to the ArcMap 10.5 program. After the path information was downloaded using OpenStreetMap, it was converted into a format that can be used in the ArcMap 10.5 program and roads were created. The current route starts with the movement of the collection vehicles from the garage and ends with their arrival at the disposal site. The distance from the disposal site to the garage is 7.7 km, and an average of 22 minutes is spent (Fig. 3).

According to the vehicle tracking system data obtained from the Karaman Municipality Cleaning Affairs Directorate, the average speed of the waste collection vehicles is 18 km/h. While calculating the route in the ArcMap 10.5 program, the

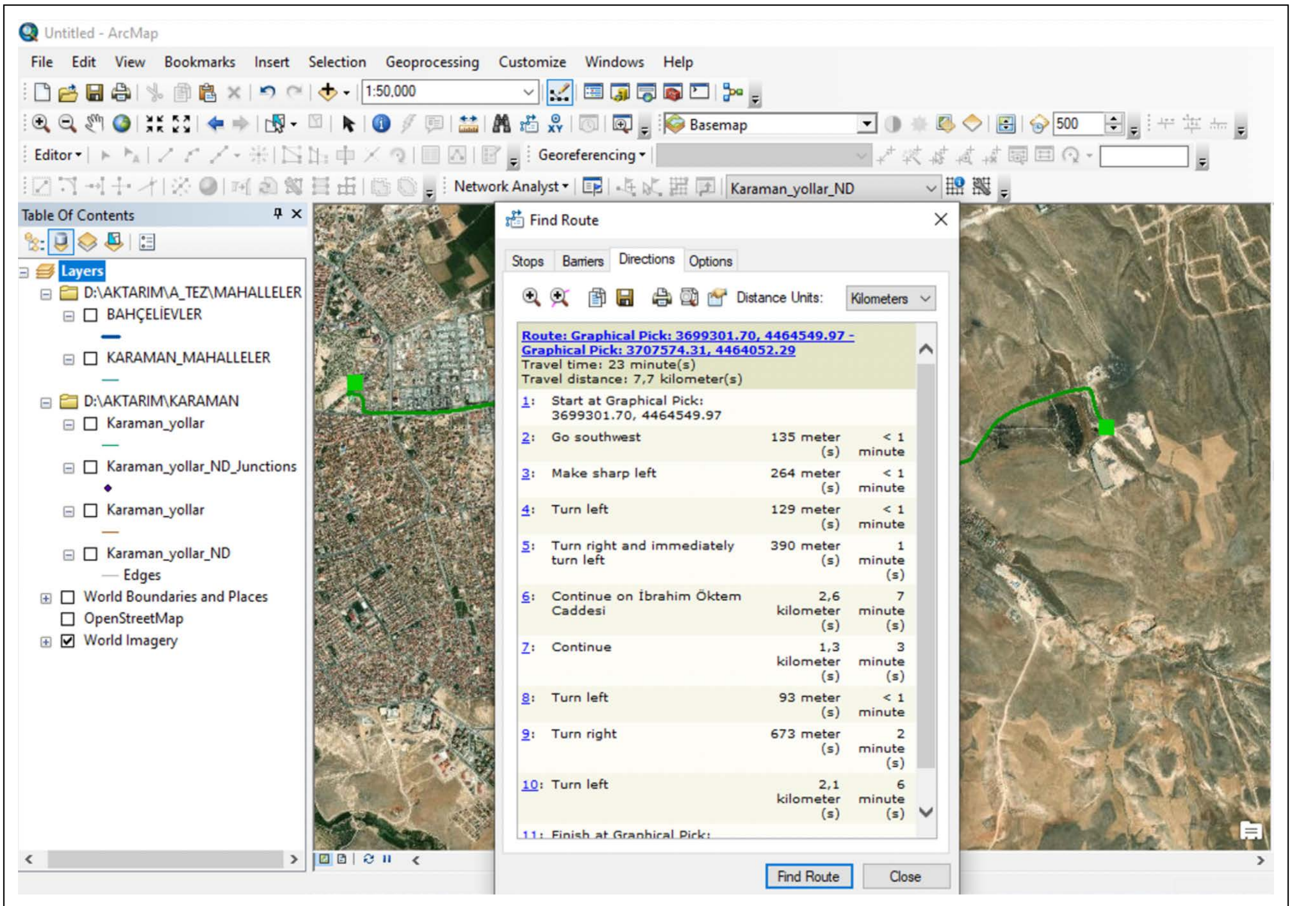

Figure 3. The distance from the landfill to the cleaning department garage.

Table 3. Optimization summary of the pilot regions

Route	Current route			Optimization			Earnings			%
	Distance (km/day)	Time (min/day)	Fuel (L/day)	Distance (km/day)	Time (min/day)	Fuel (L/day)	Distance (km/day)	Time (min/day)	Fuel (L/day)	
Atatürk	84	252	42	62	186	31	22	66	11	26
Çarşı	46	139	23	18.5	55	9	27.5	84	14	60
Sanayi	44	131	21	28	85	14	16	46	7	36
Tabduk emre	46	139	23	40	121	20	6	18	3	13
Yunus Kent sağ	43	130	21	32	97	16	11	33	5	26
Average	53	158	26	36	108	18	17	50	8	32

average speed of the vehicles was chosen as 20 km/h. The time spent at each location versus the length of the route was calculated based on this data. Atatürk locality has a route length of 84 km/day. After leaving the garage and completing its course on the route, the time to arrive at the landfill is 4 hours and 12 minutes. Çarşı location has a route length of 46 km/day. After leaving the garage and completing its course on the route, the time to reach the landfill is 2 hours and 19 minutes. The industrial site has a route length of 44 km/day. After leaving the garage and completing its course on the route, the time to reach the landfill is 2 hours and 11 minutes. Tabduk Emre locality has a route length of 46 km/day. After leaving the garage and completing its course on the route, the time to reach the landfill is 2 hours and 19 minutes. Yunus Kent Sag location has a 43 km/day route length. After leaving the garage and completing its course on the route, the time to reach the landfill is 2 hours and 10 minutes.

Optimization of Vehicle Routes

Considering the container layout in the existing 5 pilot regions, the route optimization is planned with the starting point being the Cleaning Works Directorate garage and the ending point being the sanitary landfill. The Network Analyst module of ArcMap 10.5 software was used for solid waste collection and optimum route determination. As a result of the optimization conducted in the light of this information, it seems possible to achieve an optimization of 26% for the Atatürk site, 60% for the Çarşı site, 36% for the Sanayi site, 13% for the Tabduk Emre site, and 26% for the Yunus Kent Right site. The optimization summary is provided in Table 3.

CONCLUSION

There are 4,750 containers placed on the site for the collection of urban solid waste (garbage collection) in Karaman. The number of people per container is 35. The average occupancy of the containers before they are emptied is 33%. Despite this, citizens sometimes complain about the overflow of the containers during meetings with the Karaman Municipality Cleaning Affairs Directorate. These results indicate two things: the number of containers is sufficient according to the container occupancy rate, and even more containers are placed than necessary. However, it is clear that the container layout lacks proper planning. This causes extra stops and starts for the vehicles, leading to some containers being overfilled while others remain empty. The placement of the containers on the streets should be re-planned based on the number of people per container, the population impact diameter of the container, or the optimum distance between containers [20–23].

There are 433 recycling bins placed in Karaman by a licensed company for packaging waste. Additionally, there are 5,950 indoor boxes distributed to households and workplaces. The waste volume per container is 2.58 m^3, and the container utilization factor is 129%. These results show that the existing recycling equipment is insufficient to collect the recyclable wastes in the city. Furthermore, the existing recycling containers are open, uncovered, and unprotected, making them susceptible to collection by people known as street collectors. This reduces the amount of waste that can be collected by the licensed company from the recycling containers and increases the company's costs. The number of recycling equipment in Karaman should be increased, and the containers should be modernized and protected from external interventions [22–28].

To enhance the efficiency of collecting recyclable materials, it is crucial to expand the availability of recycling bins and equipment, increase the distribution of indoor containers and recycling bags to public entities, organizations, and residential buildings, and ensure these are collected at designated times. Additionally, encouraging active involvement from individuals eager to contribute to recycling efforts is essential [29–31].

When the container density in Karaman is analyzed with the help of the ArcMap 10.5 program, the average distance between the containers is 33 meters, while the expected average distance is 73 meters. This analysis shows that the containers are too close to each other, which also explains the low container utilization factor. Container layout should be re-planned based on the population, using the container impact diameter or within the expected average distance range [7, 17].

Existing and optimized routes were created using the ArcMap 10.5 program for 5 pilot regions in Karaman. The route optimization studies have shown that an average of 32% optimization has been achieved, saving 17 km/day, 50 min/

day, and 8 L/day of fuel on average in the 5 pilot regions. In light of these results, it is possible to achieve a 32% gain in both economic and temporal aspects and in reducing the carbon footprint during the collection and transportation processes, which constitute the biggest expense item of waste management (in the range of 65–80%). Similarly, it is stated that a 27% gain in optimization studies can be achieved in the literature [7]. For the integrated waste management system to be created and progressed economically and systematically, after the container layout optimization is done, the route determination process should be carried out using systematic and scientific methods for the transportation of wastes by collecting the containers. Thus, the municipality will increase its economic gains with the Integrated Solid Waste Management system while minimizing the level of waste to be generated within the framework of zero waste [26, 29, 30].

DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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