Environmental Research and Technology
https://ert.yildiz.edu.tr - https://dergipark.org.tr/tr/pub/ert
DOI: https://doi.org/10.35208/ert.1244755

Research Article

Optimal route selection using network analysis in terms of time, cost and fuel savings: The case of İskenderun, Türkiye

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ARTICLE INFO

Article history
Received: 30 January 2023
Revised: 22 September 2023
Accepted: 28 September 2023

Key words:
GIS; Municipal Solid Waste Management; Route; Solid Waste Collection; Solid Waste

ABSTRACT

Solid waste generation has increased significantly as a result of increasing population and living standards. In this context, variables such as waste classification, amount produced, collection and transportation status, disposal method, socioeconomic status of the region include important stages in system planning. It is important to optimize these variables, waste collection route, time, cost, environmental impacts and examine the current situation. The cost of collection and processing accounts for roughly 65–80% of the total cost of the solid waste management system managed by local governments. Therefore, by optimization studies, the trash collection-transport route can significantly reduce this rate. Depreciation and fuel expenditures can be significantly reduced as a result of improvements in operational costs. Denizciler neighborhood was selected as an example of all district characteristics within the study's scope when the socio-economic, demographic, and topographic conditions of the Iskenderun district of Hatay province were evaluated. The ESRI ARCGIS software's tools have been used to test the optimization path. A 421-meter shorter route was discovered using network analysis. Considering the current route, which is 14340 meters long, a 3% improvement has been achieved with the analysis made. Garbage collection was done using the newly developed route in the study's final section. As a result, the viability of the network analysis enhancement has been evaluated in practice, and it has been discovered that time and fuel savings are realized in terms of cost.

Cite this article as: Yazıcı Karabulut B, Karabulut Aİ, Derin P, Yeşilnacar Mİ, Çakma GB. Optimal route selection using network analysis in terms of time, cost and fuel savings: The case of İskenderun, Türkiye. Environ Res Tec 2023;6(4)332–339.

INTRODUCTION

One of the most important environmental problems that directly affect human life and cause harmful effects is solid waste. As the population shows a constantly increasing trend around the world, it is inevitable that consumption should follow this rising trend together with the population. As a result, solid waste production is increasing day by day. As of 2020, according to the data of the Turkish Statistical Institute, the population of our country has been

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This paper has been presented at Sixth EurAsia Waste Management Symposium (EWMS 2022)/İstanbul, Türkiye / 24–26 October 2022.

Published by Yıldız Technical University Press, İstanbul, Türkiye

determined as 83 million 614 thousand 362 people. While around 32.3 million tons of urban solid waste is produced annually in our country, an average of 1.13 kg of solid waste is produced per person per day [1]. With the increase in population, the investment costs for the collection of solid wastes have increased.

Solid waste management is a major concern for local governments worldwide, not only because of its environmental impact, but also because waste collection services are one of the highest expenditures of municipalities in low-income countries [2]. Typically, collection costs represent 80-90% and 50-80% of the municipal solid waste management budget in low-income and middle-income countries, respectively [3]. Waste collection and transport alone accounts for approximately 50-70% of the total cost of the system. Optimum location and number of transfer stations are required for an economical and efficient collection system [4]. In particular, solid waste collection and transport activities account for approximately 50% to 70% of total solid waste management costs. Total collection costs represent 0.5% to 2.5% of per capita income for developing countries [5]. Therefore, solid waste collection and transportation is a costly business. Improvements to be made in solid waste collection routes will have a positive impact on the collection cost. In a study by İrdemez et al. [6], the process of municipal solid waste collection and transport systems in Palandöken district of Erzurum province was examined in all aspects. Studies on the characterization, amount and projection of municipal solid wastes have been carried out, and a route optimization study has been carried out by using Google earth program to determine the most suitable routes. Minimum cost systems have been developed for effective, efficient and regular collection and transport of wastes.

It is essential to design efficient and simple transport routes for collection and recovery systems (including the processing capacity of distribution points and recycling stations, disposal and transport times, staffing arrangement, etc.), based on the principles of maintaining minimum cost and hygiene standards [7]. The traditional approach to waste collection creates a fleet of trucks that collect/transfer waste from individual/common bins to treatment/disposal facilities. This is a very costly process that accounts for more than 60% of total waste management expenditure due to fees, fuel consumption, maintenance and depreciation. A study developed a GIS-based smart collection model for waste collection route in the United Arab Emirates. In this way, it was found that the system reduced the cost of waste collection by 19% compared to the traditional scenario [8]. In this context, it is possible to use a geographic information system (GIS) as a strategy to optimize collection times and reduce costs on routes [9]. The most common optimization goals are; It includes waste collection path optimization by reducing the route length, time optimization, cost optimization and environmental effects [10].

Collection and transportation of solid waste constitutes the majority of solid waste management. In the literature, it is possible to reach optimization studies with the integration of different disciplines such as environment, geomatics and industrial engineering.

In the study, an optimization study was conducted to increase the efficiency of solid waste collection in Greece. ArcGIS network analysis was used for optimization. Within the scope of the study, two different experiments were conducted. The first set of experiments (S1) dealt with collection vehicle route optimization and the second set of experiments (S2) dealt with container reallocation and route optimization. In both cases, savings were observed compared to the current operation. According to the results of the optimization study, 3% improvement in collection time for S1 and 17% improvement for S2; 5.5% improvement for S1 and 12.5% improvement for S2 in terms of distance traveled [11]. In the study [12], optimization was performed for solid waste collection and transportation operations in Safakes, Tunisia. In the optimization process using ArcGIS Network network analysis, 3 sets of experiments were created.

GIS was used [13] domestic solid waste collection and transportation works in Şanlıurfa, Suruç Municipality. With this study, it was aimed to minimize the solid waste collection and transportation process costs. It has been seen that the obtained data contributed greatly to the cost of the studies using GIS.

In the study conducted [14] the solid waste collection route optimization of Diyarbakır province, Kayapınar district, Barış neighborhood was discussed. For this study, the ant colony, which is one of the artificial intelligence samples, and the performance of genetic algorithms and GIS software were used in coordination. As a result of the study in question, different results were obtained with each method. The Ant Colony Algorithm provided the most efficient result in numerical terms, with an improvement of approximately 41%.

The Denizciler neighborhood in the İskenderun county of Hatay was chosen as a representative neighborhood for the study, and the neighborhood's current waste collection system was examined. The solid waste collection route was then attempted to be optimized using GIS. The ArcGIS solution was able to reduce the total distance by 3% as a result of the optimization research conducted to optimize using these methods. Therefore, this work will be further developed to combine various flexible computing techniques in terms of time, money and a sustainable environment.

MATERIALS AND METHODS

Study Area

To route optimization, İskenderun district, which is the most developed district in terms of industry and urbanization, was selected from 15 districts in Hatay province. The population of Iskenderun is 250 thousand 964 according to 2020 Turkish Statistical Institute data [1]. There are 45

Figure 1. Location map of the study area.

neighborhoods in Iskenderun district (Fig. 1). Denizciler neighborhood one of the neighborhoods by the sea, has a surface area of 2 million 921 thousand 200 square meters and a population of 24 thousand 617 people. The slope of the elevation profile of Denizciler neighborhood, which is one of the densely populated neighborhoods, is 15% and has an average slope of 5.7%. According to the geometric standards of the highways, the Denizciler neighborhood topographic structure (5.7%) can be considered flat. The daily waste amount was calculated as approximately 28 tons and 10,000 tons per year.

Geographic Information System and Network Analysis Tool

Geographic Information System (GIS) "designed to solve complex planning and management problems; It can be defined as the system of hardware, software and methods that enable the coverage, management, processing, analysis, modeling, and display of the data whose position in the space is determined [15–17]. Environmental management, municipal activities, transportation, health, tourism, education, agriculture, trade, defense, and security systems, etc. It has a wide usage area [15]. Network analyst tool, which is one of the GIS analyzes, was used. With the network analysis tool, many analyzes can be performed such as creating a single or multi-modal network dataset, determining the best route using a network dataset, creating a model for route analysis, transporting several orders with a vehicle fleet, network analysis using traffic data, and optimal location allocation [18, 19].

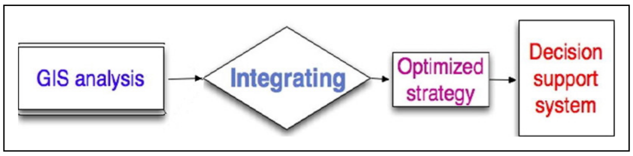

Figure 2. Optimization implementation stages.

The primary purpose of adopting GIS in solid waste management is to reduce cost and time (feasibility) and also to help planners make better decisions when designing solid waste management. From a technical point of view, geographic information systems are an up-to-date tool for modeling and optimizing service routes for which a better scenario can be proposed [19].

Methodology

The road map of Denizciler neighborhood was obtained from the Planning and Project Directorate of Iskenderun Municipality and converted into ".shp" format supported by Esri ArcGIS software from Geographic Information System applications. The coordinate data of the points where the Solid Waste containers are located were determined in the field study with the help of Iskenderun Solid Waste Association and Envitec personnel, and the coordinates of the locations of these points were transferred to Esri ArcGIS 10.8 software.

Esri ArcGIS 10.8 software was used within the scope of Denizciler neighborhood solid waste collection route optimization (Fig. 2). To be transferred to the GIS software, Denizciler neighborhood road map coordinates obtained from the Planning and Project Directorate of Iskenderun Municipality were converted to the "TUREF_TM39" coordinate system by adding direction limitation, speed limit and time limit. As a result of the field work carried out with the officials of Envitech company, which is authorized by the Iskenderun Municipality for the collection of neighborhoods in Denizciler neighborhood, the solid waste container points were recorded by GPS. This program records the coordinate data of garbage collection vehicles instantly. As a result of this study, after the locations of the containers were marked on the map, the network topology of Denizciler neighborhood was created. There are 202 solid waste collection containers available in Denizciler neighborhood. Network structure and container points of Denizciler neighborhood is shown in Figure 3.

RESULTS AND DISCUSSION

Examination of the Current Route

To determine the route and container points in Denizciler neighborhood, field work was carried out by getting on the garbage collection vehicle in the company of Envitec personnel. The garbage collection process, which started at 6:45 in the morning from Dutlu Bahçe Site in Denizciler neighborhood, took 5 hours and a total distance of 14340 meters was measured. This process is carried out regularly at the same time every day of the week. The neighborhood where the fieldwork was carried out has streets and avenues that can be considered regular.

Figure 3. Network structure and container points of Denizciler neighborhood.

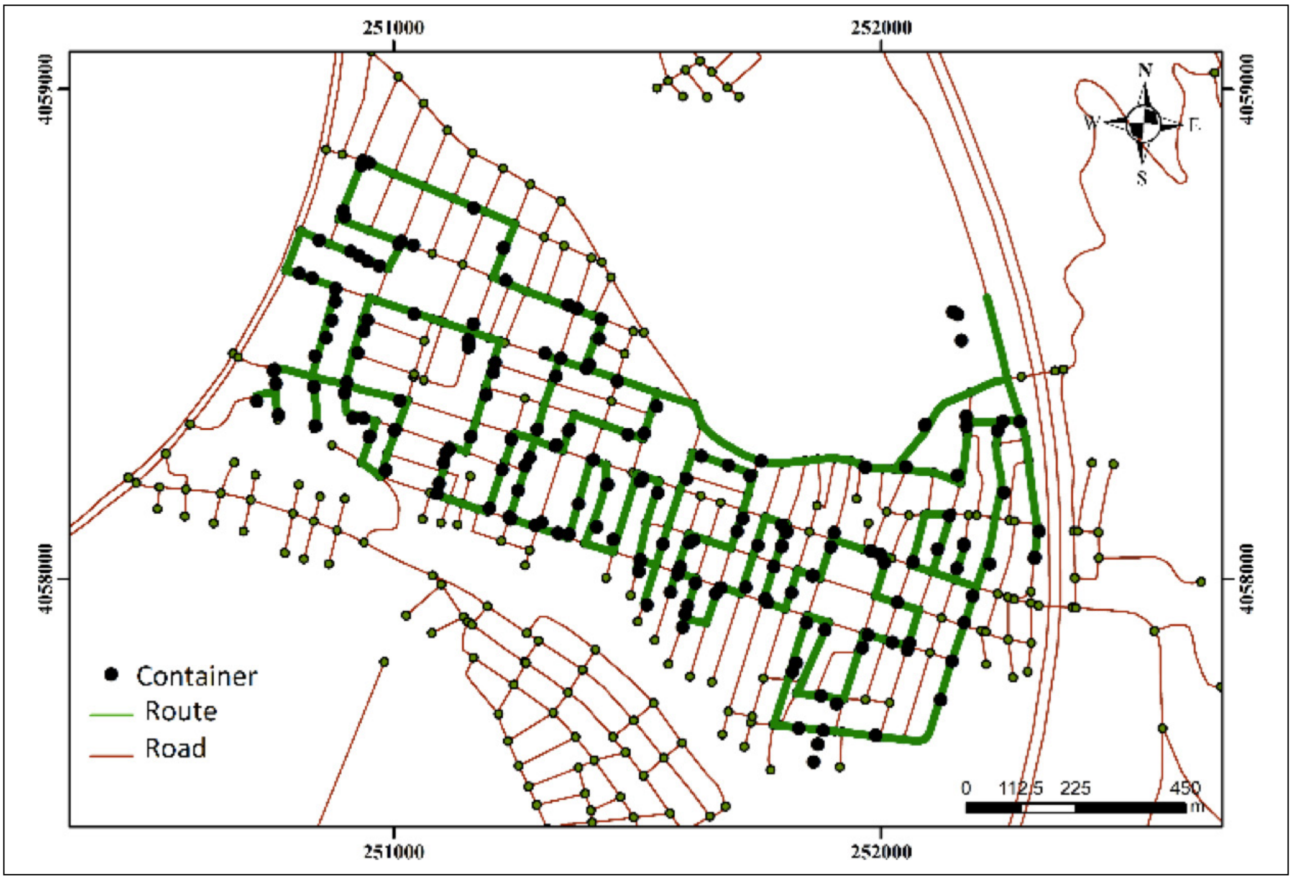

Figure 4. Road route optimization as a result of network analysis.

Figure 5. Route ranking of container points because of network analysis.

Denizciler Neighborhood Solid Waste Collection and Route Optimization Data

The physical and logical structures of networks are explained by topology. In this context, the ways in which the components that make up the networks come together with each other, the ways to be followed and the appropriate usage patterns are within the scope of the topology. The combination of parts connected by different forms creates networks. These interconnected lines are explained by network analysis. Connecting parts such as street, road, main road, avenue is within the scope of network analysis. The connection states of the networks are determined by the topological relationships explained by the nodes.

The coordinate data of Denizciler neighborhood solid waste container points were transferred the ArcGIS software, and the optimum route was obtained with Network Analysis. Route For optimization, the ArcGIS software has been tested with various tools in the software. As a result of the route optimization with network analysis, 13919 meters distance was measured (Fig. 4). Network The analysis has been obtained 421 meters shorter route. 14340 meters in length available Considering the route, a significant improvement was obtained with the analysis (Fig. 5).

A lot of research has been done to find suitable targets in waste optimization. Prabhakaran et al. [20], route optimization was performed with ArcGIS network analysis for domestic solid waste collection. The determined region was studied by dividing it into two. It was observed that the distance traveled to collect solid waste was reduced by 25% as a result of optimization. In a study by Gümüş et al. [21], it was aimed to minimize the transport cost by organizing the collection routes of the recycling facility wastes belonging to Alanya Municipality. As a result of the study, it was found that the proposed vehicle routing problem (ARP) model shortened the transport distance and provided a monthly vehicle fuel saving of approximately 12%. Sanjeevi et al. [12] an optimization study was carried out using ArcGIS application in Chennai, one of the major metropolitan cities in the southeast of India. After developing a spatial database for the whole of Chennai with 200 nodes, 13 solid waste transfer stations were identified through optimization studies using ArcGIS. This optimization process has reduced the distance traveled by 9.93%. In the study conducted by Ağaçsapan (2016) [22] Geographic Information Systems (GIS) were used in the selection of the waste transfer stations in Eskişehir province. The characteristics of the area where the wastes are managed, which differ according to the characteristics of the environment in which they are produced, are taken into consideration. In this context, GIS application was used in the sustainable realization of waste management and in determining the most suitable area for the environment and human health in line with the data available while determining the field of activity.

Table 1 shows the number of containers and the distances between them at the stops on the route formed as a result

Table 1. The mathematical model of the routes in the study

Container sorting and cumulus distance					
Container 1	0,00	Container 69	5283,18	Container 137	9234,30
Container 2	2,32	Container 70	5283,18	Container 138	9266,86
Container 3	54,48	Container 71	5348,67	Container 139	9407,69
Container 4	482,39	Container 72	5404,11	Container 140	9557,90
Container 5	533,97	Container 73	5450,73	Container 141	9592,25
Container 6	542,37	Container 74	5520,92	Container 142	9654,29
Container 7	911,68	Container 75	5549,84	Container 143	9724,80
Container 8	914,01	Container 76	5664,76	Container 144	9744,61
Container 9	1043,54	Container 77	5693,42	Container 145	9744,99
Container 10	1180,24	Container 78	5792,03	Container 146	9796,78
Container 11	1302,72	Container 79	5839,97	Container 147	9819,75
Container 12	1323,62	Container 80	5898,60	Container 148	9880,66
Container 13	1410,96	Container 81	5970,41	Container 149	9882,89
Container 14	1410,96	Container 82	6122,35	Container 150	9998,98
Container 15	1536,14	Container 83	6250,26	Container 151	10000,08
Container 16	1683,24	Container 84	6391,68	Container 152	10080,36
Container 17	1809,36	Container 85	6418,71	Container 153	10082,77
Container 18	1859,17	Container 86	6419,01	Container 154	10163,93
Container 19	1861,20	Container 87	6566,03	Container 155	10373,64
Container 20	2030,29	Container 88	6621,48	Container 156	10373,80
Container 21	2108,43	Container 89	6624,76	Container 157	10453,55
Container 22	2262,60	Container 90	6779,53	Container 158	10453,73
Container 23	2429,67	Container 91	6907,86	Container 159	10731,88
Container 24	2480,97	Container 92	6992,75	Container 160	10818,21
Container 25	2555,02	Container 93	6994,07	Container 161	10878,36
Container 26	2628,69	Container 94	7059,24	Container 162	10904,45
Container 27	2628,69	Container 95	7157,80	Container 163	10907,24
Container 28	2819,53	Container 96	7222,61	Container 164	11031,52
Container 29	2937,00	Container 97	7251,82	Container 165	11075,84
Container 30	2953,02	Container 98	7253,24	Container 166	11112,67
Container 31	2959,32	Container 99	7301,74	Container 167	11152,14
Container 32	3005,28	Container 100	7320,25	Container 168	11152,55
Container 33	3178,26	Container 101	7391,94	Container 169	11176,75
Container 34	3196,48	Container 102	7397,37	Container 170	11233,28
Container 35	3197,11	Container 103	7402,47	Container 171	11260,76
Container 36	3282,36	Container 104	7465,32	Container 172	11415,08
Container 37	3357,68	Container 105	7518,19	Container 173	11415,69
Container 38	3550,77	Container 106	7536,84	Container 174	11415,69
Container 39	3583,86	Container 107	7619,79	Container 175	11415,69
Container 40	3710,01	Container 108	7621,66	Container 176	11484,31
Container 41	3747,15	Container 109	7677,90	Container 177	11503,09
Container 42	3799,22	Container 110	7680,95	Container 178	11523,38
Container 43	3839,58	Container 111	7830,91	Container 179	11549,51
Container 44	3854,50	Container 112	7873,56	Container 180	11634,15
Container 45	3985,87	Container 113	7934,88	Container 181	11634,67
Container 46	4104,89	Container 114	8053,36	Container 182	11642,19
Container 47	4132,22	Container 115	8123,04	Container 183	11669,34
Container 48	4152,31	Container 116	8123,04	Container 184	11822,24
Container 49	4251,30	Container 117	8213,68	Container 185	11851,66
Container 50	4281,30	Container 118	8249,74	Container 186	11952,14
Container 51	4393,48	Container 119	8287,74	Container 187	11977,17
Container 52	4395,15	Container 120	8403,53	Container 188	11993,51
Container 53	4474,92	Container 121	8480,55	Container 189	12241,43
Container 54	4548,93	Container 122	8544,45	Container 190	12385,91
Container 55	4566,20	Container 123	8627,07	Container 191	12386,77
Container 56	4633,45	Container 124	8744,54	Container 192	12477,94
Container 57	4677,76	Container 125	8773,72	Container 193	12615,59
Container 58	4680,11	Container 126	8774,93	Container 194	12635,68
Container 59	4732,75	Container 127	8817,38	Container 195	12687,97
Container 60	4754,66	Container 128	8837,49	Container 196	12746,05
Container 61	4756,87	Container 129	8847,17	Container 197	12803,50
Container 62	4877,12	Container 130	8919,77	Container 198	13241,93
Container 63	4965,49	Container 131	8921,40	Container 199	13242,00
Container 64	5024,18	Container 132	9012,18	Container 200	13474,38
Container 65	5044,97	Container 133	9060,69	Container 201	13475,12
Container 66	5163,31	Container 134	9081,95	Container 202	13880,02
Container 67	5189,61	Container 135	9218,80	Container 203	13919,04
Container 68	5234,00	Container 136	9222,08		

Table 2. Comparison of route optimization data

Data	Current route	Route optimization	New route	Net gain
Time	5 hours	4 hours 42 minute	4 hours 47 minute	0.13 minute
Distance	14340 m.	13919 m.	14000 m.	340 m.

of the Route Optimization model. Before starting the study, an interview was held with the relevant municipality personnel in the study area. As a result of this meeting, it was learned that 1 vehicle in the study area is sufficient for solid waste collection. Therefore, the capacity of vehicle was not taken into account in the route optimization that constitutes the method of this study.

Comparison of Route Optimization Data

Route optimization with network analysis calculated the current route as 4 hours 42 minutes and 13919 meters. Solid waste collection was carried out by applying the route formed as a result of route optimization in the GIS. With the use of the re-determined route after reflecting these data on the field, the time to reach the last point of the solid waste collection vehicle, which started from the first container, was 4 hours and 47 minutes, and the total distance was measured as 14000 meters (Table 2). As a result of the optimization study, a real gain of 18 minutes and 340 meters emerged. This daily time and distance gain for the solid waste collection vehicle operating every day of the week will be 126 minutes and 2380 meters per week, 540 minutes and 10200 meters per month, 6570 minutes and 124100 meters per year.

It was evaluated that the difference between the time and distance obtained by network analysis and Route Optimization and the time and distance obtained by reflecting these data to the field is due to the arbitrary relocation of containers, the containers are not full and the traffic situation in dead-end streets may vary.

CONCLUSIONS

The fieldwork, which was initiated from Denizciler neighborhood Dutlu Bahçe Sitesi at 06:45 in the morning to examine the current route, lasted 5 hours and a total of 14340 meters of road was measured. As a result of the optimization study, a real gain of 18 minutes and 340 meters emerged. This daily time and distance gain for the solid waste collection vehicle operating every day of the week will be 126 minutes and 2380 meters per week, 540 minutes and 10200 meters per month, 6570 minutes and 124100 meters per year. The labor force gain that will occur because of the shortening of the existing route will lead to an increase in productivity for the company. On the other hand, efficiency in fuel consumption will increase as solid waste collection vehicles travel less distance. As another result of this situation, exhaust gas emission will decrease, and it will have less impact on environmental pollution. Since the depreciation shares of vehicles on a yearly basis will decrease, maintenance and repair costs will also decrease.

Acknowledgements

This study was financially supported by Harran University Scientific Projects Research Coordinator (HUBAP) under grant no. 21233.

DATA AVAILABILITY STATEMENT

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

ETHICS

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

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