



Analysis of municipal solid waste collection using GIS and multi-criteria decision aid

Louati Amal¹ · Le Hoang Son² · Habib Chabchoub³ · Hanene Lahiani⁴

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Abstract

Global average temperature increases and causes extreme weather events, killing millions of people and affecting economic stability. Municipal solid waste (MSW) is one of the primary factors that contribute to climate change that is the main concern of various municipalities in the world. In this paper, a two-step systematic approach is proposed to analyze municipal solid waste collection (MSWC) in Sfax, the second most populated city in Tunisia. In the first step, three feasible waste collection scenarios were suggested and have gained the consensus of decision makers and stakeholders. In the second, a geographic information system–based multi-criteria decision aid approach is proposed to identify the most appropriate scenario. Firstly, the Network Analyst function in ArcGIS is used to determine the optimal routes with the traveling distances and operational time of vehicles associated to each scenario. Secondly, a ranking of scenarios is produced by ELECTRE III method. Six pseudo criteria such as fuel consumption cost, gas emission, reliability, road length, and compatibility with the national energy policy were taken into account. The results suggest a relatively efficient and environment-friendly scenario where all vehicles start their trips from the depot, collect garbage from the gather sites, and unload waste at a transfer station then travel back to the depot. The methodology can be adopted into similar contexts to improve the effectiveness of MSW collection through the systematic use of GIS.

Keywords Municipal solid waste collection · Geographic information system · Multi-criteria decision aid

Introduction

From 1901 to 2012, mean average surface temperature rose by 0.89 °C. The global average temperature is predicted to further rise by another 0.3 to 0.7 °C between 2016 and 2035. This global heat increase is known to affect sustainable development in many different ways. The United Nation Environment Programme (UNEP) report declares that extreme weather events, which are prone to become severer and more frequent, can cause devastation. The world has witnessed over 10,000 natural and industrial disasters and dozens of major conflicts killing millions and affecting many more (Chang et al. 2009). Consequently, UNE advises that greenhouse gas emissions must be sharply reduced (UNEP 2014). Indeed, the world has to find ways to minimize these emissions. One alternative is domestic waste management. Chang et al. (2009) states that the concentration of population in cities has direct influence on increasing quantities of *municipal solid waste* (MSW). According to Son (2014), MSW is one of the primary factors that contribute greatly to climate change and global warming.

✉ Le Hoang Son
sonlh@vnu.edu.vn

Louati Amal
louatiamal@gmail.com

Habib Chabchoub
habib.chabchoub@aau.ac.ae

Hanene Lahiani
hanene.lahiani@aau.ac.ae

¹ Faculty of Economics Sciences and Management, University of Sfax, Sfax, Tunisia

² VNU Information Technology Institute, Vietnam National University, Hanoi, Vietnam

³ College of Business, Al Ain University of Science and Technology, Abu Dhabi, United Arab Emirates

⁴ College of Education, Al Ain University of Science and Technology, Abu Dhabi, United Arab Emirates

Douaud (2010) confirms that the drawbacks of road transport are important. In fact, this kind of transportation consumes much oil and fossil fuels that it turns into dangerous substances like CO₂ and greenhouse gas. Indeed, 1 kg of gasoline or diesel emits 3.2 kg CO₂ when burnt.

In this research, our interest is the MSW collection and transportation problem in Sfax city. Sfax is the second largest city in Tunisia regarding the number of population. It is also one of the most polluted cities in that North African country with 24 towns. Tunisia's population counts 10.778 million inhabitants generating 2.423 million tons of MSW, which is equivalent of 0.815 kg/day per capita in the urban areas (GmbH 2014). Tunisia's MSW generation growth rate is 2.5%, the final destination of 70% of which is the landfill (see Table 1 for details).

Kchih (2007) indicates that Sfax city has a high pollution rate and high population density with 272,801 inhabitants being located in the city center (municipality of Sfax) which explains the high average waste quantity (0.702 kg/inhabitant/day). In consequence, experts are searching in waste management. They have divided the task of waste management into two main stages. The first stage is the collection-transportation from waste sources to the transfer stations. This is completed by the municipality of Sfax which outsources the task to different public and private collection operators. The second stage is the transportation of waste from the transfer stations to the landfill. This is completed by the National Agency for Waste Management (ANGed).

In this paper, we concentrate on the first stage. The current or real MSW collection scenario in Sfax involves the use of heterogeneous types of vehicles such as agricultural tractors, dumper trucks, and automated vehicles like compactor vehicles. Sfax is administratively divided into seven boroughs; each borough is under the responsibility of an assistant manager and a few workers. To further narrow down the focus of this paper, the industrial borough named "Elboustene" is selected for the case study. The selection is based on several criteria. First, with 0.944 kg of MSW per capita per day, this borough generates a bigger MSW quantity than its neighbor boroughs; also, it stretches over a total area of 315 ha with 17,446 inhabitants, 217 industrial units, and many health, financial, and public institutions (GmbH 2014). Similar to the rest of the boroughs, MSW in the Elboustene borough is collected by a private operator (GmbH 2014) (Fig. 1).

Table 1 Variation in MSW composition, Tunisia (GmbH 2014)

Type	Organic	Plastic	Paper/ cardboard	Metal	Glasses	Others
Ratio (%)	68	11	10	4	2	5

Related works

Geographical information system (GIS) is a powerful tool used to provide detailed spatial information and analysis with the support of routing algorithms such as Dijkstra in ArcGIS for searching optimal solutions. Many existing works (e.g., Tavares et al. 2009; Son 2014; Zhang et al. 2015a, b; Son and Louati 2016; Amal et al. 2018, 2019; Zsigraiova et al. 2013) used vehicle routing algorithms to solve shortest-path problems. For instance, the case study of Malakahmad et al. (2014) was performed in Poh city. The authors used geographical information system (GIS-ArcView) to investigate solid waste collection route optimization. Five routes were selected and optimized to reduce the length of the routes and the collection time. Results reported up to 22% length minimizations in the routes. The collection duration was reduced by 2332 s. Other works treated the waste collection route from transfer station to disposal site like Khan and Samadder (2014) addressed a mini review on various aspects of MSW management employing the GIS coupled with other tools. They also dealt with how GIS can help optimize routes for the collection of solid wastes from transfer stations to disposal sites for the purpose of reducing the overall cost of solid waste management.

There are other researches such as Chandrakant and Patel (2015) who utilized the GIS for zone A under Pimpri Chinchwad Municipal Corporation by using ArcGIS3.2, optimizing the waste transportation routes and reallocating the bins by minimizing the traveled distance and collection time. The authors presented three scenarios: (i) the existing scenario in the Pimpri Chinchwad City, (ii) its improvement through route optimization using ArcGIS Network Analyst, and (iii) optimizing route after the reallocation of bins. The obtained results show that the second scenario is the optimal one. Besides, the case study of Gallardo et al. (2015) was carried out in Castellón (Spain). The authors presented a structured methodology that allows local authorities or private companies using MSW to design their own MSW management plan depending on the data available. This paper combines the planning methodology with the geographic information systems to show the final results in thematic maps which facilitate their interpretation. The proposed methodology is a useful tool to organize MSW collection routes. In fact, it is important to design an MSW management system and decide the number of pre-collection containers and their locations all over the town, which reduces the cost and the length of the collection routes by minimizing the number of containers. The authors used the ArcGIS 10.1 software to locate the storage points. Unlike our case, other works treated the transfer station problem such as in Sanjeevi and Shahabudeen (2016) in which the objective is to minimize the total collection distance using 13 routes connecting 13 ward centroids and one transfer station. The generated waste is collected from the same locations. First, the municipal waste is transported to the garbage

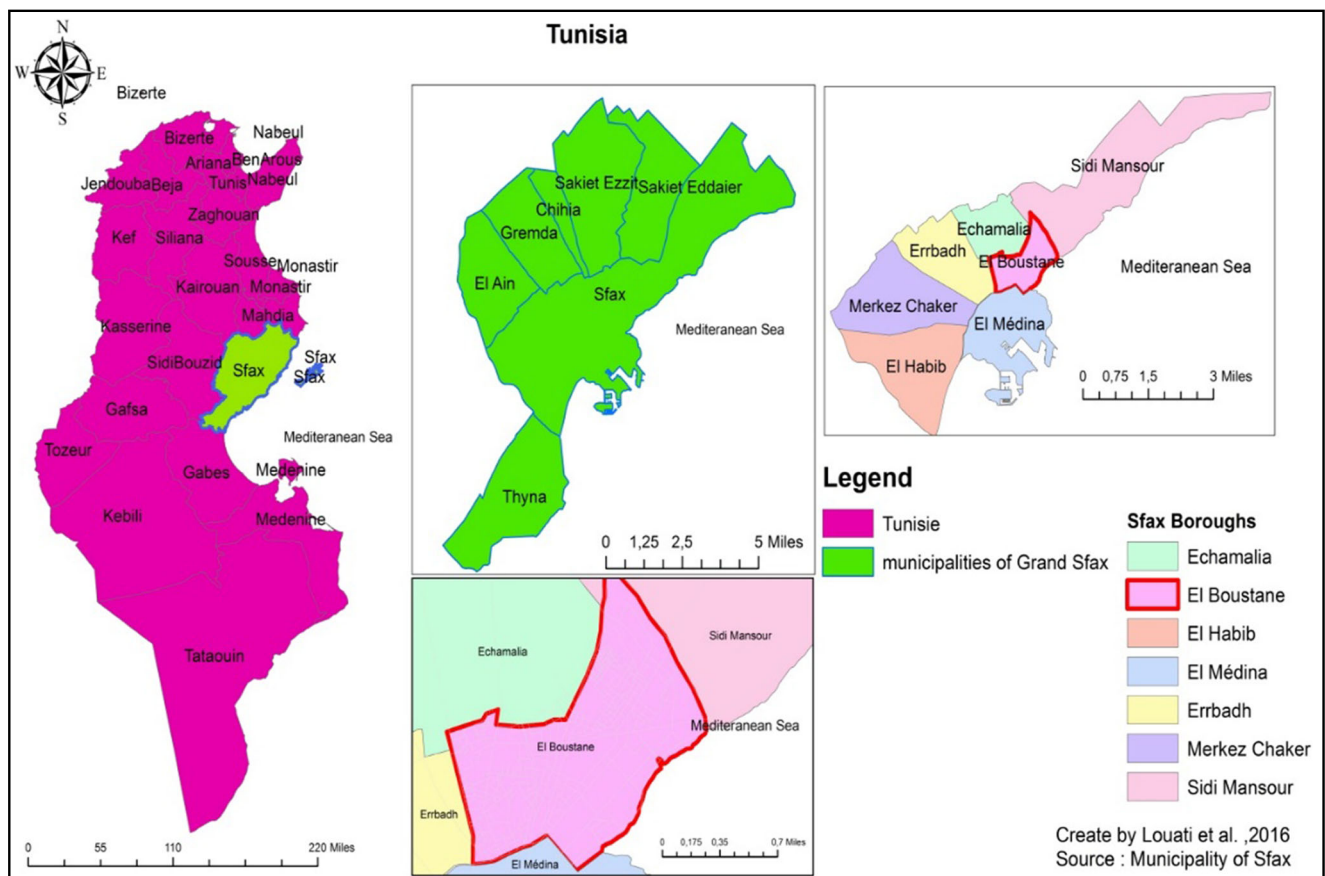


Fig. 1 MSW in Sfax city, Tunisia

bins by tricycles and wheelbarrows. Then, it is taken to the transfer stations by bulk garbage open tippers (light and heavy motor vehicles). Finally, it is transferred to the dumping sites using a variety of light and heavy vehicles. The disposal is by open dumping. The authors used the GIS application to identify the optimum routes for 13 selected wards. The traveled distance traveled as reduced by 9.93% for the 13 wards. Various researchers employed the Network Analyst function in ArcGIS that implements the Dijkstra routing algorithm to search optimal solutions. Han (2015) presented the literature review based on a classification of waste collection. The author analyzed the major contribution of Waste Collection Vehicle Routing Problem (WCVRP) in literature and analyzed different methods and techniques used to solve it. Bonomo et al. (2012) showed that ArcGIS is a good choice for the analysis of MSW collection.

Our objectives are to determine optimal routes with the traveling distances and operational time of vehicles associated to each proposed scenario using ArcGIS and identify the most appropriate scenario using multi-criteria decision aid methods. There have been a number of multi-criteria decision aid methods for waste management. Pires et al. (2011) integrated the analytic hierarchy process (AHP) with TOPSIS to determine essential

weighting factors for alternative screening and ranking to help decision makers in Setúbal Peninsula, Portugal, for the selection of the best waste management with respect to environmental, economic, technical, and social criteria. There are various multi-criteria decision aid methods for waste management. For instance, Ekmekçioğlu et al. (2010) employed the fuzzy multiple criteria analysis (MCA) to select a disposal method and site for MSW. They proposed a modified fuzzy TOPSIS methodology and compared the alternatives to find the best disposal method alternative at Istanbul, Turkey. In the second stage, the same methodology was applied to determine the best disposal site location. Maimoun et al. (2016) utilized two techniques, namely TOPSIS and simple additive weighting (SAW), to rank alternatives in fuel waste collection industry in the USA. The study relied on a multi-criteria approach taking into account multi-level environmental and financial decisions. A sensitivity analysis showed that the fuel price is the most important criteria for some alternatives. Soltani et al. (2015) presented a review of MCDA methods for MSW problems, which indicated that AHP and ELECTRE are the most common approaches used by multiple stakeholders, experts, and governments/municipalities. Karagiannidis and Moussiopoulos (1997) applied multi-criteria decision aid method (ELECTRE III) to rank five

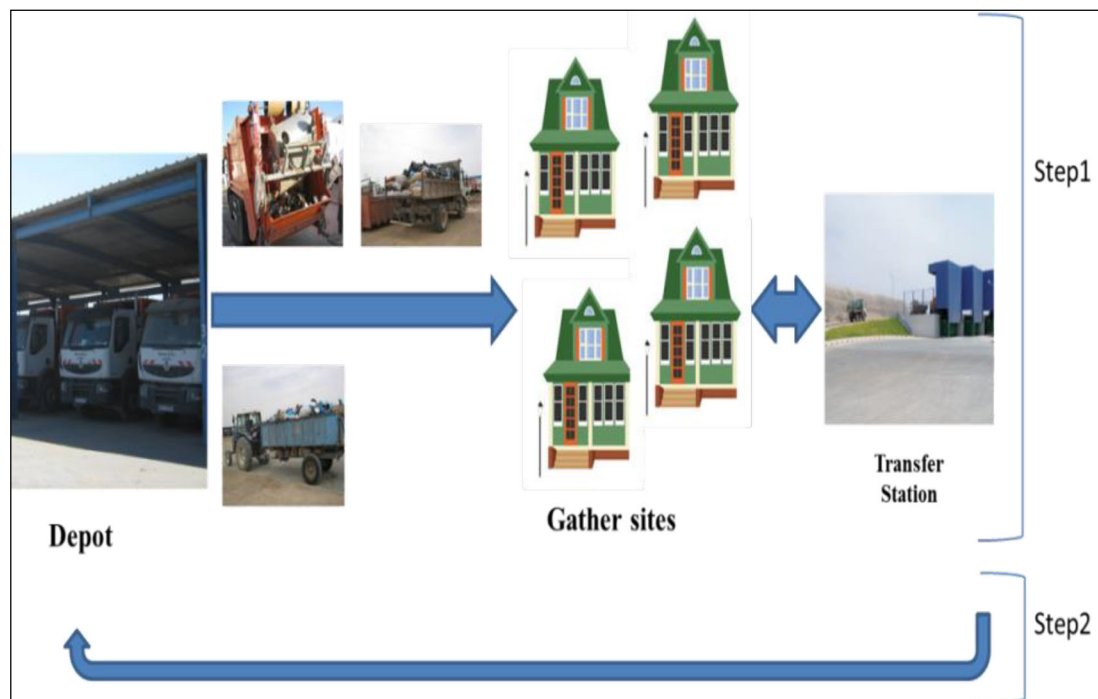


Fig. 2 The tour of each vehicle

selectively composed alternatives for the integrated management of household waste in the Greater Athens Area, Greece, by taking into account 24 evaluation criteria. A sensitivity analysis was also demonstrated. Hokkanen and Salminen (1997) used the ELECTRE III decision aid to choose a solid waste management system in the Oulu region, Finland. The obtained result showed that over \$10 million would be saved during the time covered in the plans of 1997–2010. The increase in the amount of recovered waste can be estimated at 30% (total amount of 60%). The analysis of MSW results using the multi-criteria decision aid methods, especially ELECTRE, was indeed inevitable.

In this paper, we analyze the MSW collection in the city of Sfax, Tunisia, using geographic information system and the multi-criteria decision aid method namely ELECTRE III. Three waste collection scenarios are proposed and analyzed by ArcGIS to determine the route maps of vehicles. ELECTRE is then utilized to identify the best scenario for the MSW collection in Sfax. The findings are significant for the planning and management of municipal solid waste in case studies having similar waste collection scenarios.

Table 2 Vehicle characteristics

Vehicle types	Capacity (t)	Quantity
Compactor vehicle	7.4	1
Dumper truck	2.3	1
Agricultural tractor	1.6	2

Materials and methods

Case study

Waste in Sfax can be classified into two types: The first type is household waste produced by three main sources, namely houses, hotels, and streets, whereas the second type is from other sources such as markets, offices, restaurants, hospitals, institutions, prisons, barracks, barns of and livestock farms. These sources are called the *gather sites*. The current real scenario of SFAX, especially at “Elboustene” borough, includes a depot (the starting place of vehicles), many gather sites, and many collection centers (or transfer stations). The vehicles are responsible for collecting waste to the transfer stations. In fact, the agricultural tractor can carry up to 1.6 t of waste. The dumper truck can transport 2.3 t of waste, while the compactor vehicle has the maximal capacity of carrying around 7.4 t of waste. Our case study contains one depot, two transfer stations, and four vehicles including two agricultural tractors, one dumper truck, and one compactor vehicle.

Drivers start their first trip from the depot at the same time. After loading waste at some gather sites and the total load reaches the vehicle capacity, waste will be unloaded at a collection center and the vehicle will start a new route. Heterogeneous vehicles are used so that different operations are applied to various types of vehicles (Table 1 and Fig. 2).

The vehicles start their trips at 06:00 in the morning from the depot and finish at the depot again no later than 13:00. They must go to either transfer station (1 or 2) before coming

Table 3 Vehicles and bins of MSW scenario at Sfax

Nodes	Capacity (t)	Quantity	Time
Depot	0	1	Start time 06:00 a.m. End time 1:00 p.m.
Transfer station 1	250	1	Waiting time 0
Transfer station 2	60	1	Waiting time 0
Gather site	0.4	39	Load/unload time 15 min for each gather site

back to the depot. So, the collecting waste process can be divided into two steps. In the first step, the vehicles start at the depot; they collect waste at the gather sites and unload it at a transfer station. In the second step, the vehicles start at the transfer station and return to the depot. Table 2 shows that there are three types of vehicles namely agricultural tractor, dumper truck, and compactor vehicle whose capacities are 3528 kg, 5071 kg, and 16,315 kg, respectively. In Elboustene, there are three types of node depot, transfer station (1 and 2), and gather sites (39 gather sites).

Network analysis in ArcGIS

In this paper, GIS-aid decision process is used. GIS is a software program that creates displays and analyzes geospatial data, solves vehicle routing problem (VRP) for waste collection problems, and shows the results.

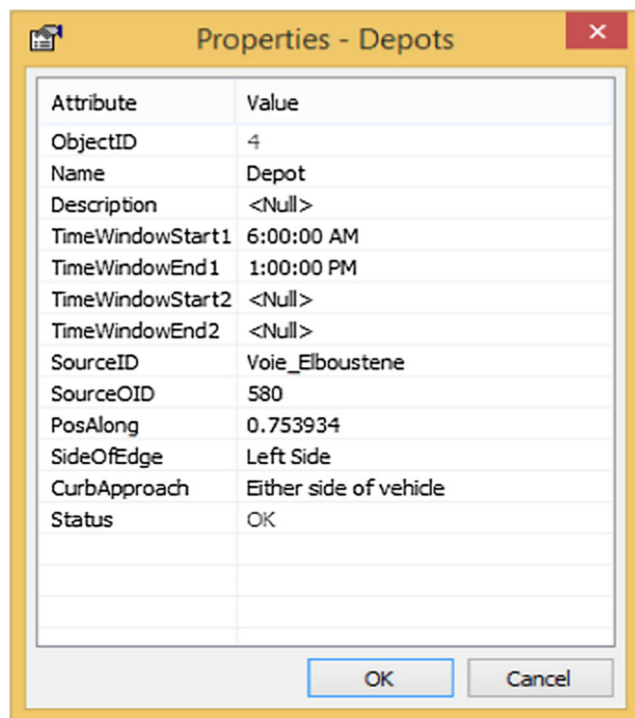


Fig. 3 Depot information

ArcGIS Desktop 10.1 is a GIS-aided method that provides detailed information about spatially referenced events and phenomena. It has many extensions, such as the ArcGIS Network Analyst which solves the network problem as a route, service area, and closest facility; OD Cost Matrix solvers; VRP; or location-allocation problem. The routing solvers are based on the Dijkstra algorithm (Dijkstra 1959) for finding the shortest paths. The analysis layer stores the results after well defining the properties, data, and solved operations. The classic Dijkstra algorithm solves shortest-path problems on undirected, non-negative, and weighted graphs. The performance of the Dijkstra algorithm is further improved by using better data structures. The algorithm models the locations anywhere along an edge, not just on junctions.

The VRP solver starts by generating an origin-destination matrix of shortest-path costs between all collection nodes (gather site) and depot locations along the network. Using this cost matrix, the algorithm constructs an initial solution by inserting the nodes, one at a time, onto the most appropriate route. The initial solution is then improved by re-sequencing the nodes on each route as well as by moving nodes from one route to another and exchanging nodes between routes. The heuristics used in this process are based on a Tabu search and are proprietary (Esri 2006). The VRP needs to honor real-world constraints including vehicle capacities, delivery time windows, and driver specialties. The VRP produces a solution that honors those constraints while minimizing an objective function composed of operating costs and user preferences.

VRP produces a solution that meets those constraints while minimizing an objective function composed of operating costs and user preferences. The parameters of vehicle routing function used in ArcGIS are as follows:

- (i) Capacities of the depot, nodes, and transfer stations.
- (ii) Time criteria like the starting and ending time in the depot and transfer station.
- (iii) The quantity of waste in each node.

Thus, the total traveling time in each road segment should be considered as the total traveling time for each trip including the driving time of a vehicle in the route, the loading node time, and the waiting time in a transfer station. The driving time of the vehicle in the route is calculated by considering the

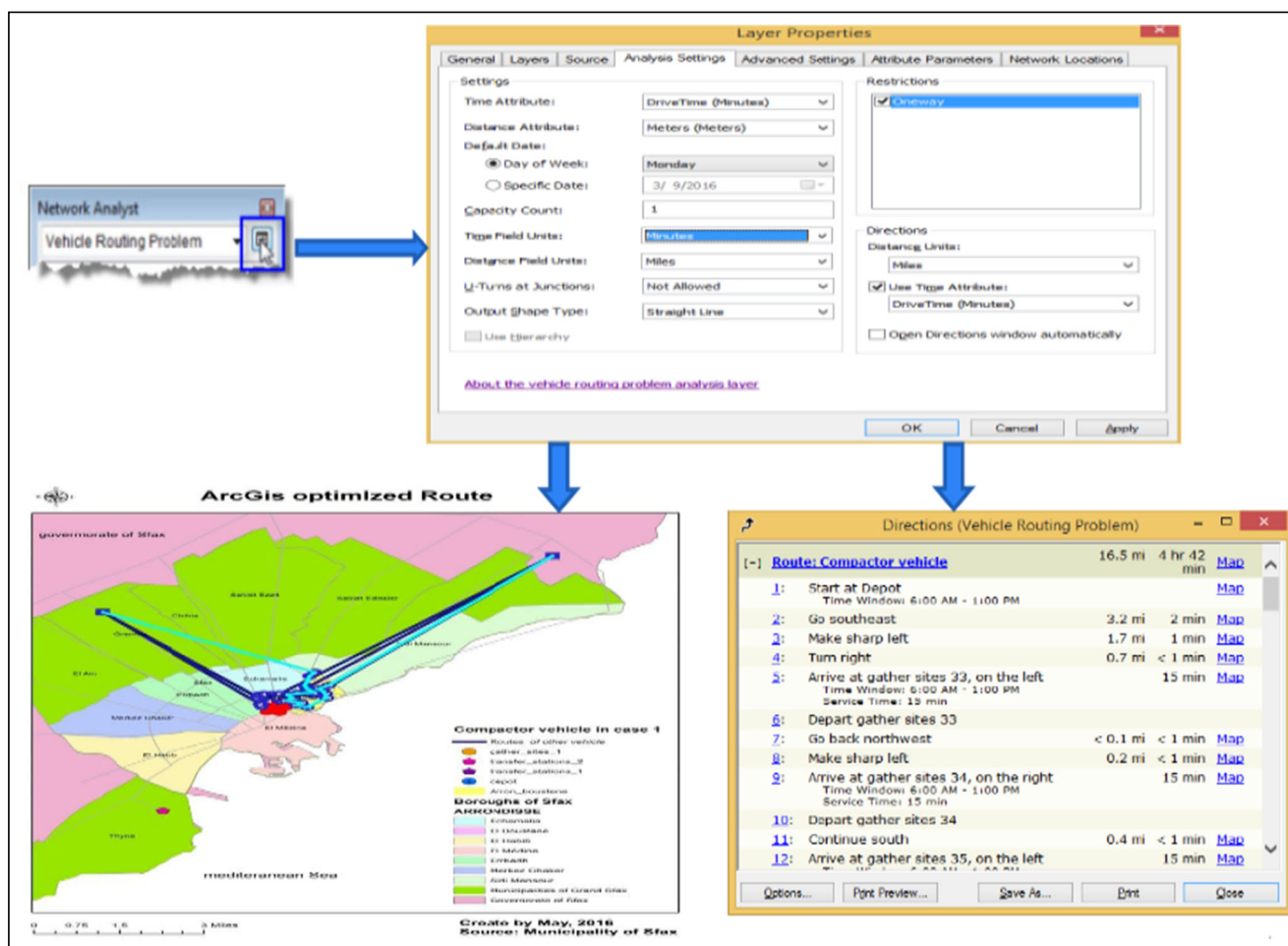


Fig. 4 Using Network Analysts in ArcGIS

length of road and the speed of the vehicle in each road. The time of waste collection would be the total time consumed by the vehicle to collect waste from all loading nodes. The length is taken into account in each road segment. Some parameters are then selected as in Table 4 and Fig. 2. All the parameters generated from our real-life case study are presented in Tables 2 and 3 and Fig. 3.

In the ArcGIS software, experts use the Network Analyst to solve VRP problem. This feature shows only the starting and final points of the trip. Although the starting point and the final point of the route are the same, the model and scenario must ensure that all vehicles pass through the transfer station 1 or 2 before returning to the final point, which is not supported in the VRP function. To solve this problem, the two steps described below should be followed:

Step 1: The cars start at the depot, to collect the waste from the collection sites. Then, they move to the transfer station in order to empty the waste. In this step, the starting point is the depot, while the final point of the trip is the transfer station.

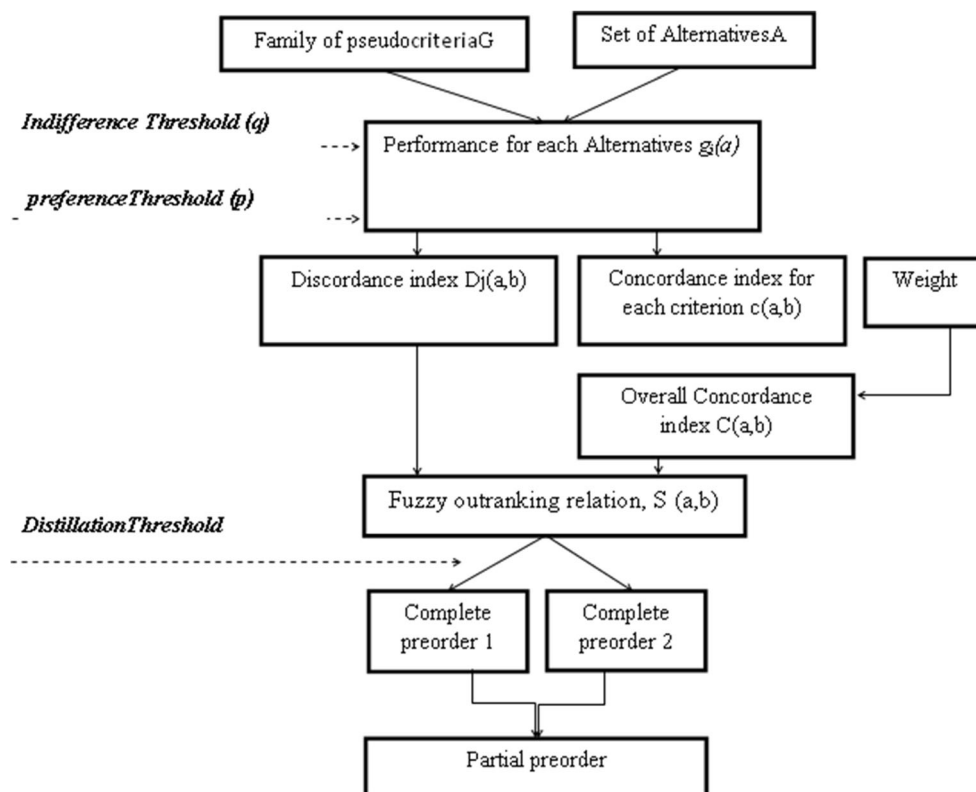
Step 2: The vehicles go from the transfer station to the depot. In this step, the starting point is the transfer station, while the endpoint is the depot.

Figure 4 shows these steps: (i) A network analysis layer represents a network problem and (ii) the problem is solved using the vehicle routing function in ArcGIS for GIS data of MSW collection in Sfax (layers proprieties) and problem parameters, and (iii) ArcGIS represents the solution (map and directions list).

Proposed scenarios

We present the scenario and data collected in the Elboustene borough, Sfax city. The current waste collection scenario shows that waste collection methods currently used in Elboustene know many difficulties. In order to meet these difficulties, a method that optimizes waste collection time at Elboustene should be found. The technique proposed is called the Network Analyst function in ArcGIS. In the first step, the vehicles will start at the depot. Then, they collect waste at the gather sites and unload it at a transfer station. In the second step, the vehicles start at the transfer station and come back to the depot. In our case study scenario, there are two transfer stations. ArcGIS cannot automatically find which transfer

Fig. 5 General structure of ELECTRE III



stations are suitable in each vehicle’s itinerary. Therefore, the three scenarios are proposed.

In this section, we introduce three waste collection scenarios which are further evaluated and compared with the real one:

1. The first scenario: All vehicles start from the depot, collect garbage from the gather sites, and unload waste at transfer station 1. They then return to the depot.
2. The second scenario: All vehicles start their trips from the depot, collect garbage from the gather sites, and unload waste at transfer station 2. They then return to the depot.
3. The third scenario: All trippers start from the depot and collect garbage from the gather sites. Then, the dumper truck and agricultural tractors unload waste at transfer

station 1, while the compactor vehicle unloads waste at transfer station 2 because its capacity is the largest among all. Then, they all return to the depot.

The question here is as follows: What is the most effective scenario of MSW collection in Sfax city in terms of environment, cost, and other criteria? In order to answer this question, we firstly use Network Analyst function in ArcGIS to determine the optimal routes of vehicles including total traveling time and distances of all vehicles as well as the route maps.

The current MSW collection process (scenario 0) in Sfax is done manually in the sense that routes of vehicles are not optimized by any method but based solely on the experience of drivers. Yet, it is shown that using computerized methods, such as ArcGIS, can reduce the total traveling distances and

Fig. 6 Criteria for the solid waste collection and transportation problem

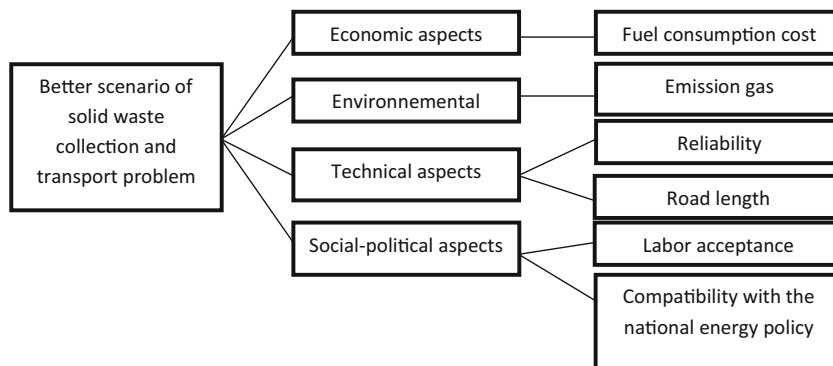


Table 4 Route's parameters

Attribute	Value	Description
Name	Agricultural tractor 1	Name of the vehicle
StartDepotName	Depot	The vehicle starts at the depot.
EndDepotName	Transfer station 1	The vehicle unloads the waste at transfer station 1.
EarliestStartTime	6 a.m.	The vehicle can start to load the waste as soon as the depot opens at 6:00 a.m.
LatestStartTime	6 a.m.	The vehicle must start as soon as possible.
Capacities	3528 lb	Agricultural tractor 1 can load a maximum of 3528 lb of waste.
MaxOrderCount	39	The maximum number of gather sites that can be loaded with waste by the agricultural tractor 1.
MaxTotalTime	420 min	Due to workday constraints, drivers cannot have a work shift of more than 7 h (420 min).

operational time. Many previous researches used a vehicle routing algorithm, such as Dijkstra in ArcGIS, to derive optimal solutions (Karadimas et al. 2007; Tavares et al. 2009; Son 2014; Zhang et al. 2015a, b). It was proven that ArcGIS is a good choice for the analysis of MSW collection (Bonomo et al. 2012).

ELECTRE

Karagiannidis and Moussiopoulos (1997) described the ELECTRE family and its characteristics. Soltani et al. (2015) stated that ELECTRE is an outranking method that uses a complex mathematical process to rank or present leading alternatives. ELECTRE III outranks alternatives by comparing pairs (a_i, a_n) to each other (Rogers 2000) (Fig. 5).

Each pair of actions is characterized by an outranking relation $(a S b)$ where S can be I (a and b are indifferent), Q (a is weakly preferred to b), or P (a is strictly preferred to b). The outranking relation is determined based on the difference between the performance of alternatives and the value given to different thresholds. We evaluate the credibility degree (between 0 and 1) of this hypothesis through two indices: concordance index and discordance index. Two complete pre-orders are then constructed via two distillation procedures (descending and ascending). The intersection of these two pre-orders results in a final rank.

The complex problem of a multi-criteria choice is usually formulated by

- Set of alternatives $A = \{a_1, a_2, \dots, a_i, \dots, a_n\}$: a given set of actions to rank.

In our case, we have four alternatives or four waste

Table 5 The average truck release coefficients (Hokkanen and Salminen 1997)

Component	CO	NO _x	HC	Particles
Emission factor (g/km)	5.0	15.5	1.3	1.7

collection and transportation scenarios in Sfax city, Tunisia.

- Set of criteria $G: \{g_1, g_2, \dots, g_j, \dots, g_n\}$: a given set of coherent family of criteria: We have six pseudo-criteria such as fuel consumption cost, gas emission, reliability, road length, compatibility with the national energy policy objectives, and labor acceptance (Fig. 6).
 1. Fuel consumption cost: The average fuel consumption value given by the private company (currently in charge of waste collection) in our case study is 53 l/100 km for the dumper truck and agricultural tractors and 39 l/100 km for compactor vehicle, and the diesel litter price is \$0.57.
 2. Gas emission: Hokkanen and Salminen (1997) and Hickman (1999) presented the methodology for calculating gas emission as in Table 5.
 3. Reliability: Estimating the technical reliability of each alternative could only be made by experts, because the criteria depend on many factors like policy of a private company.
 4. Road length: The road length of the current scenario is given by the GPS (global positioning system) as reported by the private company concerned.
 5. Compatibility with the national energy policy objectives: The municipality of Sfax, with the aid of other partners described in (GmbH 2014), is willing to control and optimize costs of waste management in conformity with the objectives of the national strategy on waste management.
 6. Labor acceptance: A labor questionnaire carried out in the company was drawn upon. In that survey, a number of workers have scaled the alternative from 0 to 5.
- Set of evaluations $g_j(a): g(a) = (g_1(a), g_2(a), \dots, g_n(a))$ include the evaluation of the alternative on all the criteria. This evaluation can be quantitative or qualitative. $g_j(a_i)$ represents the evaluation of the alternative $a \in A$ on criterion g_j
- Set of weights w : Weight of criteria expresses the importance of criteria.

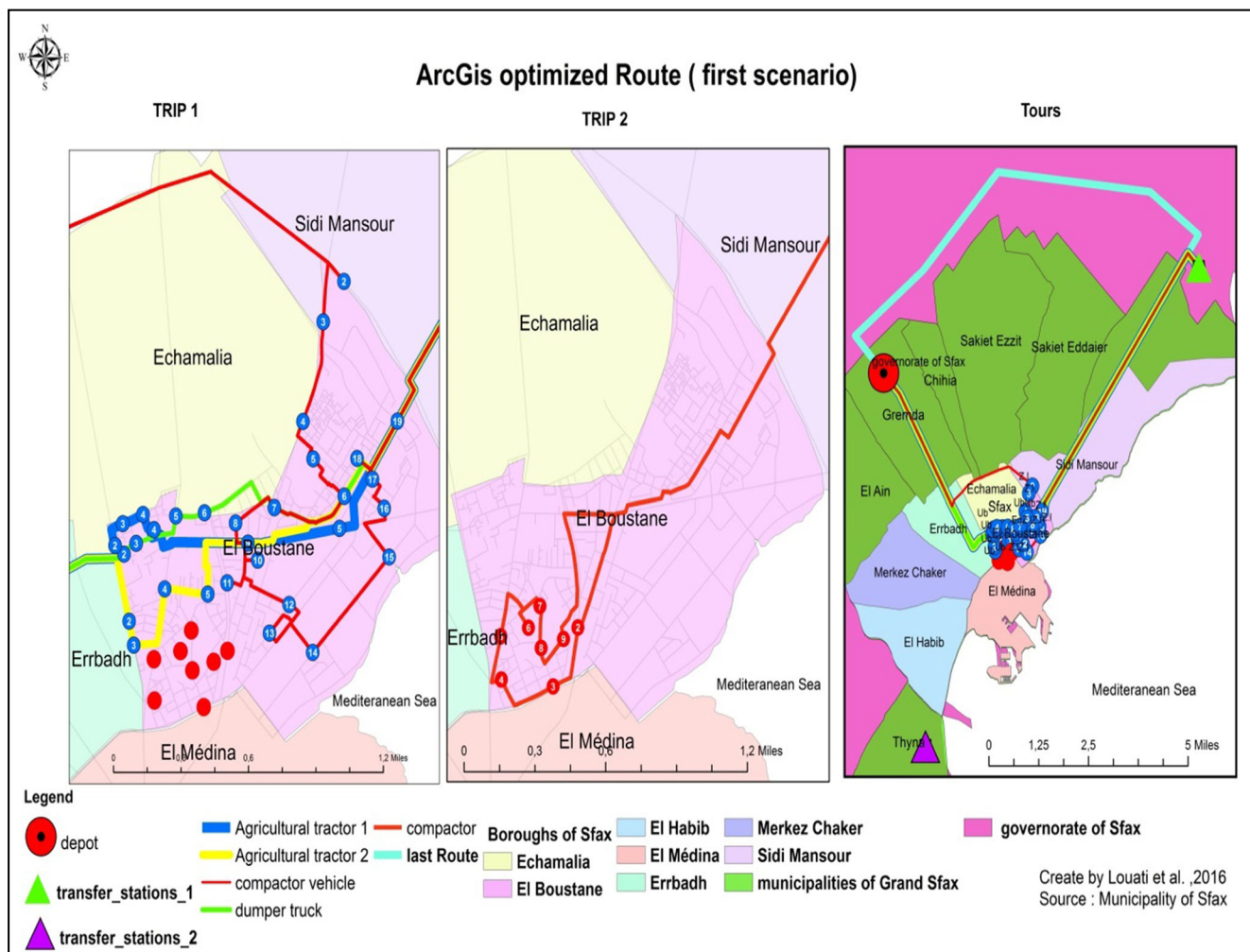


Fig. 7 Optimal route map of the first scenario

- Thresholds: With the use of thresholds, the pseudo-criterion model allows to consider such weaknesses as imprecision and hesitation which may negatively affect performance.
- Indifference threshold (q): Below this threshold, the performance of two actions can be judged by the decision maker as “indifferent.”
- Preference threshold (p): Above this threshold, one of two actions can be “preferred” by the decision maker.
- Veto thresholds (v): the smallest difference of performances from two actions. This threshold usually allows decision makers to consider if the worst of the two actions (in one aspect) is as good as the better one mainly if its performances on all other levels are better.

- Distillation threshold $S(\lambda)$: for credibility degree.

We present some steps for ELECTRE III as follows:

Step 1: Calculate the concordance index of each pair of alternatives. This index measures the arguments in favor of the statement “ a_i outranks a_n ” where $g_j(a)$ represents the evaluation of the alternative a on criterion j and q_j and p_j are, respectively, the indifference and preference thresholds. w_j is the weight of criterion j . $c(a_i, a_n)$ is the outranking degree of alternative a and alternative b under criterion j .

Table 6 ArcGIS results of the first scenario

Tripper	Agricultural tractor 1	Agricultural tractor 2	Dumper truck	Compactor vehicle
Traveling distances (km)	21.1	21.7	21	74.6
Operational time (h)	1.19	1.19	1.34	7.04

Table 7 ArcGIS results of the second scenario

Tripper	Agricultural tractor 1	Agricultural tractor 2	Dumper truck	Compactor vehicle
Traveling distances (km)	32.8	33.8	31.7	57
Operational time (h)	1.15	1.15	1.29	6.55

Step 2: Calculate the discordance index of each pair of alternatives. This index measures the affirmation “ a_i outranks a_n ” if there exists a very strong opposition by at least one criterion for the alternatives a_n to calculate this discordance index using the vector threshold (Karagiannidis and Moussiopoulos 1997).

Step 3: Calculate the degree of outranking defined by $S(a_i, a_n)$.

Step 4: The exploitation of the outranking relations to construct a partial pre-ranking with two complete pre-rankings is constructed through a distillation procedure (descending and ascending). The descending distillation procedure is to choose the best alternative, and then, it classifies the other alternatives from the best to the worst. The ascending distillation procedure allows the selection of the wrong alternative; then, it classifies the other actions from the poorest to

the best. The final order could be obtained after the downward and upward orders (Hokkanen and Salminen 1997).

Results

In this section, the waste collection data of Sfax city presented in Tables 2, 3, 4, and 5 used as input in GIS-aid method as ArcGIS Network Analyst for deriving optimal routes of vehicles accompanied with traveling distances and time. Those results are then evaluated by ELECTRE III. Firstly, we illustrate the results provided by the first scenario where all vehicles start at 06:00 a.m. from the depot, collect garbage from the gather sites, and unload waste at transfer station 1. For

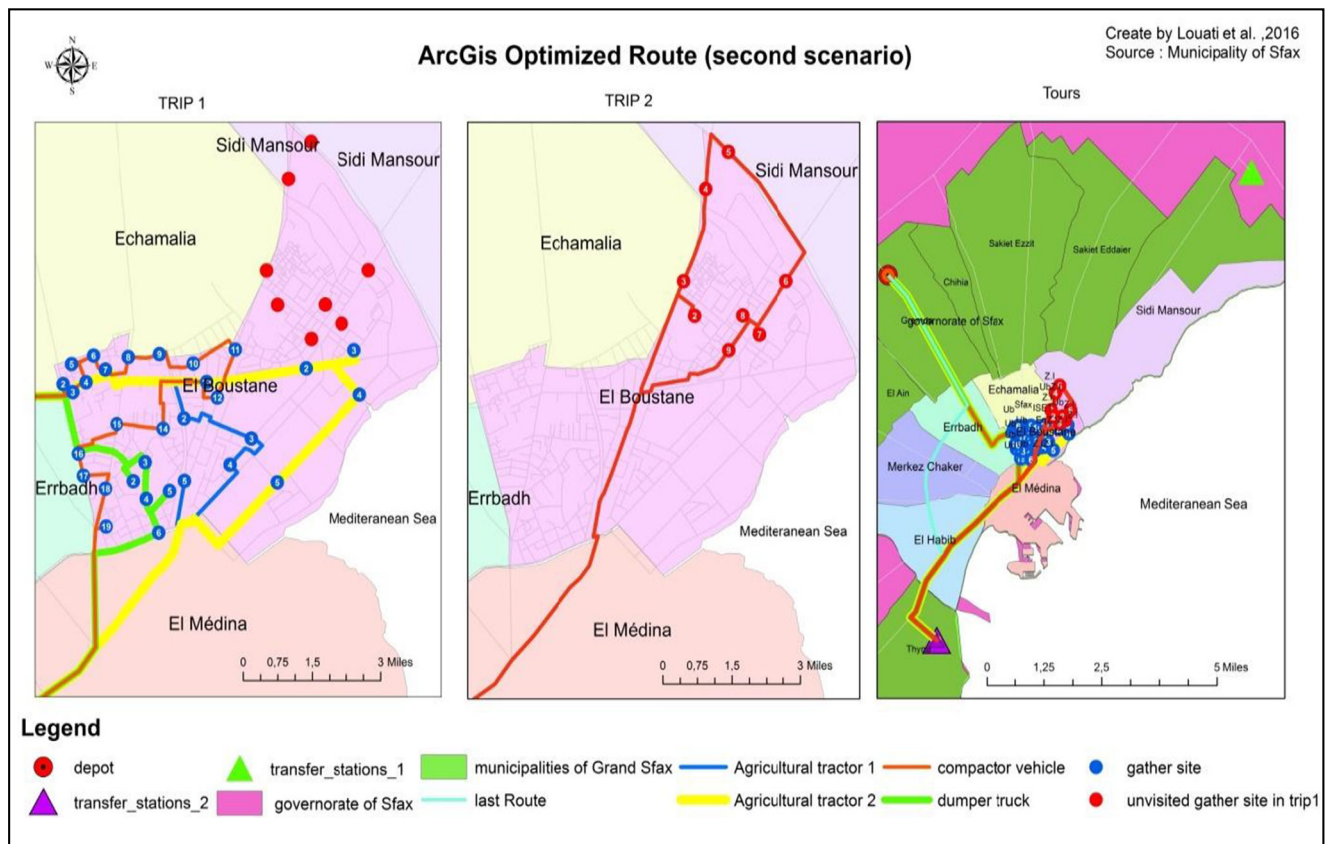


Fig. 8 Optimal route map of the second scenario

Table 8 ArcGIS results of the third scenario

Vehicle	Agricultural tractor 1	Agricultural tractor 2	Dumper truck	Compactor vehicle
Traveling distances (km)	40.7	40.5	40.7	58
Operational time (h)	1.19	1.19	1.34	6.56

instance, a tour can consist of two trips for the compactor vehicle as depicted below (Fig. 7):

- Trip 1: depot -> gather site 33 -> gather site 34 -> gather site 35 -> gather site 36 -> gather site 32 -> gather site 39 -> gather site 38 -> gather site 37 -> gather site 26 -> gather site 19 -> gather site 25 -> gather site 21 -> gather site 24 -> gather site 23 -> gather site 28 -> gather site 30 -> gather site 31 -> gather site 29 -> transfer station 1. Finishing trip 1, the compactor vehicle unloads waste at transfer station 1 and starts trip 2.
- Trip 2: gather site 20 -> gather site 10 -> gather site 7 -> gather site 8 -> gather site 5 -> gather site 4 -> gather site 6 -> gather site 3 -> transfer station 1. To finish trip 2, compactor vehicle unloads waste at the transfer station 1

again. Then, it goes to the last route towards the depot. In the first trip, the agricultural tractor 1 visited four gather sites like agricultural tractor 2. Dumper truck visited 5 gather sites, while the compactor vehicle visited 18 gather sites. There were eight unvisited gather sites; that is why a second trip made by the compactor vehicle is necessary. Table 6 and Fig. 7 show the ArcGIS results of the first scenario.

Made by the ArcGIS viewer, the map describes the network analysis solution for vehicle routing problem illustrated in Fig. 7.

Secondly, in the second scenario, all vehicles start at 06:00 a.m. from the depot, collect garbage from the gather sites, and

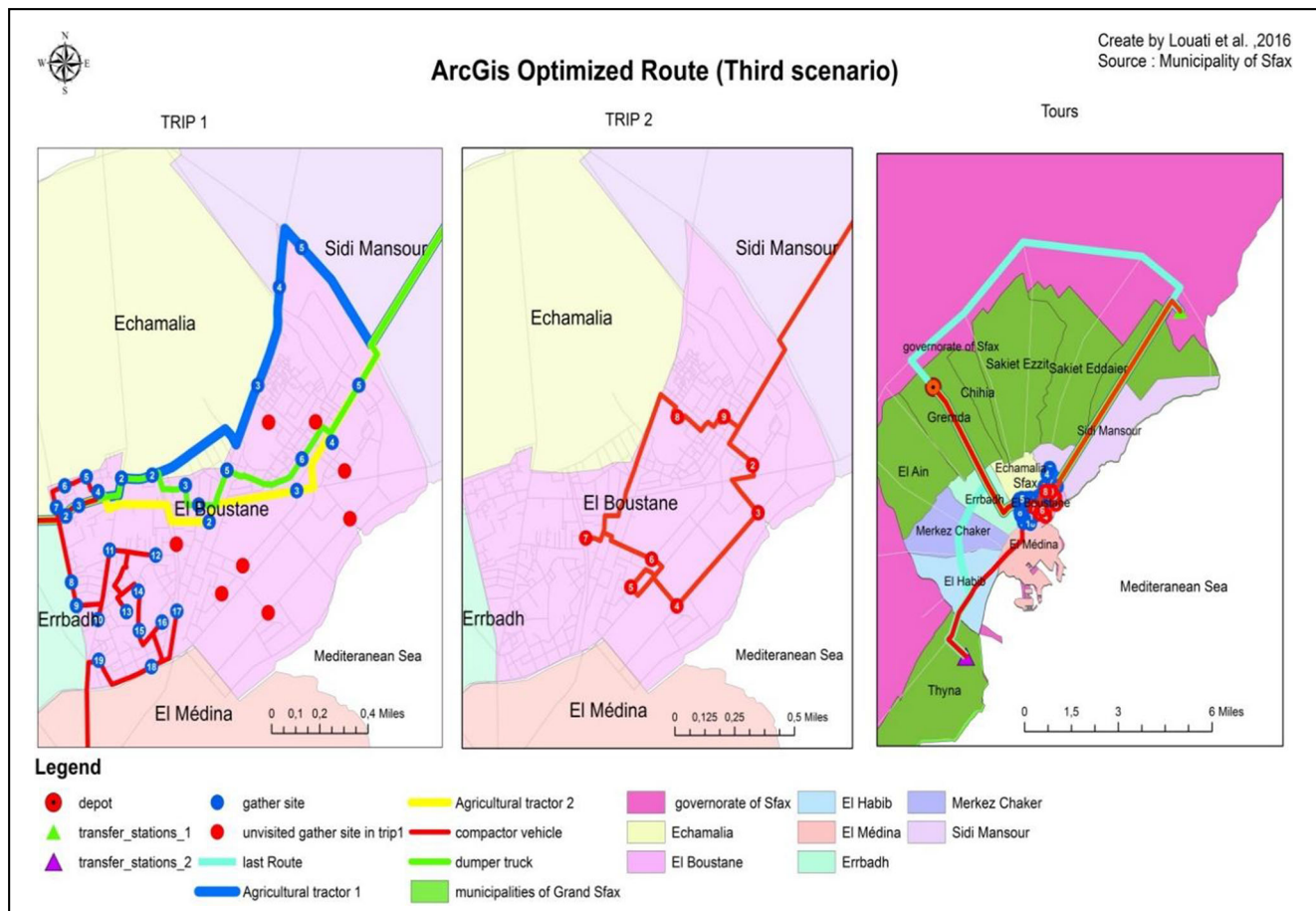


Fig. 9 Optimal route map of the third scenario

Table 9 Comparison of the results

Vehicle	Real scenario	Scenario 1	Scenario 2	Scenario 3
Total distances (km)	166.75	197	155.2	180
Total time (h)	14.10	11.23	10.9	11.33

unload it at the transfer station 2. For instance, a tour can consist of two trips for compactor vehicle as follows (see Table 7 and Fig. 8):

- Trip 1: depot -> gather site 16 -> gather site 15 -> gather site 14 -> gather site 17 -> gather site 18 -> gather site 13 -> gather site 1 -> gather site 22 -> gather site 38 -> gather site 39 -> gather site 26 -> gather site 37 -> gather site 9 -> gather site 2 -> gather site 12 -> gather site 11 -> gather site 8 -> gather site 7 -> transfer station 2. Finishing trip 1, compactor vehicle unloads waste at the transfer station 2 and starts trip 2.
- Trip 2: gather site 36 -> gather site 35 -> gather site 34 -> gather site 33 -> gather site 29 -> gather site 30 -> gather site 31 -> gather site 32 -> transfer station 2. Finishing trip 2, it unloads waste at the transfer station 2 again; then, it goes to the last route towards the depot.

Thirdly, in the third scenario, all vehicles start from the depot at 06:00 a.m. and collect garbage from the gather sites. A tour consists of two trips: The dumper truck and agricultural tractors unload at transfer station 1 in trip 1. The compactor vehicle unloads waste at transfer station 2 in the trip 1 and trip 2. After unloading at transfer stations, all vehicles take the last route to the depot (see Table 8 and Fig. 9).

Lastly, we compare the results provided in the three scenarios with those of the real case scenario which is currently deployed in Sfax, as shown in Table 9.

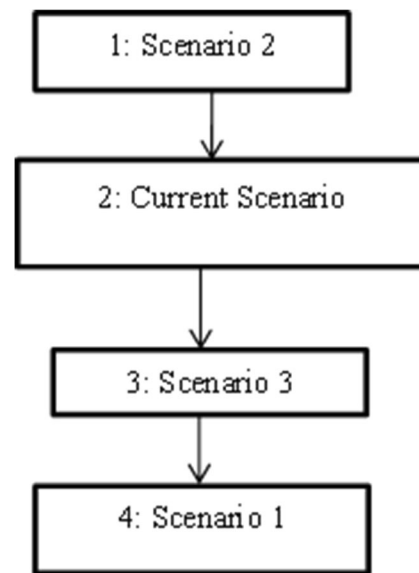


Fig. 10 Final outranking

Discussions

The results prove that using computerized methods to determine optimal routes of vehicles can reduce total traveling distances and operational time compared with the current method of MSW collection in Sfax based solely on the experience of drivers. Nonetheless, using ArcGIS for GIS data of Sfax accompanied with the information of waste quantities of all nodes (gather sites, transfer stations, etc.) is not enough to derive a good solution. That is to say, the Network Analyst function (or the vehicle routing function using the Dijkstra algorithm) in ArcGIS ignores the constraints of waste quantity of nodes and vehicles, for instance if a vehicle comes to a gather site, it must check whether its remained capacity is large enough to load (parts of) the waste quantity of that node. Analogously, the total current waste quantities of a vehicle after leaving a node must be less than or equal to capacity of the vehicle. ArcGIS ignores the multiple depot constraints

Table 10 Weight values

Alternatives	Criteria					
	Road length (km)	Fuel consumption cost (\$)	Emission gas (g/km)	Reliability	Compatibility with the national energy policy objectives	Labor acceptance
Weights	0.2	0.23	0.17	0.2	0.1	0.1
Direction of preference	Decreasing	Decreasing	Decreasing	Increasing	Increasing	Increasing
Real scenario	166.75	40.18	3918.625	5	2.5	4
Scenario 1	196.98	49.75	4628.99052	5	2.5	3.5
Scenario 2	155.30	39.07	3649.49008	3	5	5
Scenario 3	179.92	44.62	4228.11389	2.5	2.5	3

Table 11 The qualitative scales of the performance of an action on every criterion

Level	Value
Very bad	1
Bad	2
Sufficient	2.5
Average	3
Satisfactory	3.5
Good	4
Very good	4.5
Excellent	5

(e.g., End Depot Name in Table 4). There are also many constraints that were not taken into account in ArcGIS; making the vehicle routing function pays much attention to the map’s topology (which means shortest paths between nodes) rather than the waste collection itself. However, in order to use Dijkstra within the context of real-world transportation data, it must be modified to represent user settings such as waste quantity and network constraints while minimizing a user-specified cost attribute.

We analyze the results in Table 9 by ELECTRE III, the outranking method to rank leading alternatives. Weight value of each criterion and type of threshold are presented in Table 10. The final outranking is presented in Fig. 10. From those results, we make a sensitivity analysis to verify the credibility degree in which the veto threshold was set sufficiently high to eliminate any veto effects for all criteria. Table 10 presents the direction of preference (i.e., a preference direction is said to be increasing if the greater values are preferred). In this case, the objective is to maximize the criterion. However, the preference direction is said to be decreasing if, on the other hand, the smaller values are

preferred. Here, the objective is to minimize the criterion, the set of actions (i.e., the current scenario and three proposed scenarios), the set of weights of criteria (i.e., the importance of criteria, for example, the importance of the road length criterion is 20%, fuel consumption cost 23%, labor acceptance 10%), and the evaluation of the alternative on all the criteria, such as was proposed by a quantitative scale described in Table 11.

We analyze the results obtained by ELECTRE III and make a sensitivity analysis to discover any conflicts among criteria, to fix priorities, to identify potential compromise, and to verify the robustness of this technique with respect to weight values. There are different criteria such as the economic, social, political, technical, and environmental which means we have imprecise data. Some discussions are made below. In ELECTRE, thresholds are the linear formulation $\alpha_j g_j(a) + \beta_j$. So, for each of the three thresholds, we should identify α and β coefficients which are essential factors of the analysis of robustness.

$$q_j(g_j(a_i)) = \alpha_j g_j(a_i) + \beta_j \text{ belonging to } [-1; 1];$$

$$p_j(g_j(a_i)) = \alpha_j g_j(a_i) + \beta_j \text{ belonging to } [-1; 1]; v_j(g_j(a_i)) = \alpha_j g_j(a_i) + \beta_j \text{ belonging to } [-1; 1];$$

For performance $g(a)$ action, the thresholds (preference, indifference, and veto) are calculated as $\alpha \times g(a) + \beta$. The threshold varies as a function of the performance if the coefficient α is other than 0. The decision maker has to identify the value of the coefficients α and β for every type of threshold and for every criterion. The α and β coefficients must not return a negative value for a threshold. Besides, along the scale of a criterion, the indifference threshold must remain lower than the preference threshold itself lower than the veto threshold.

Rogers and Bruen (1998) have demonstrated that for action a , $q_a < 2p_a$. The thresholds q , p , and v act like quantification where the margin of error spoils the data and the free choice of the decision maker where $g_j(a)$ is alternative a ’s evaluation value on criterion j . $p_j(g_j(a))$ and $q_j(g_j(a))$ can be solved so that threshold values can be constant (β makes zero and α has to be determined) or proportional to $g_j(a)$ (β has to be determined, and α makes zero) or a combination of these two (both β and α have to be determined) (Roy et al. 1986). First, we have set thresholds with arbitrary levels. Then, we modified some sensitivity analysis values to see their impact and to lessen their subjectivity and their arbitrariness. In the sensitivity analysis of the ELECTRE III, the ranking method depends on the choice of indifference and preference thresholds. For this test, the following hypotheses have been considered:

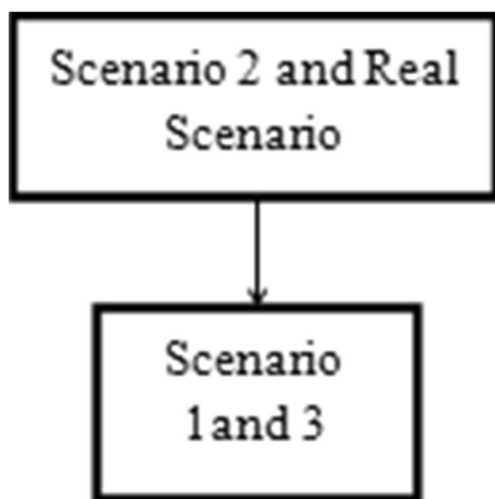


Fig. 11 The outranking of scenarios with equal weights of each criterion

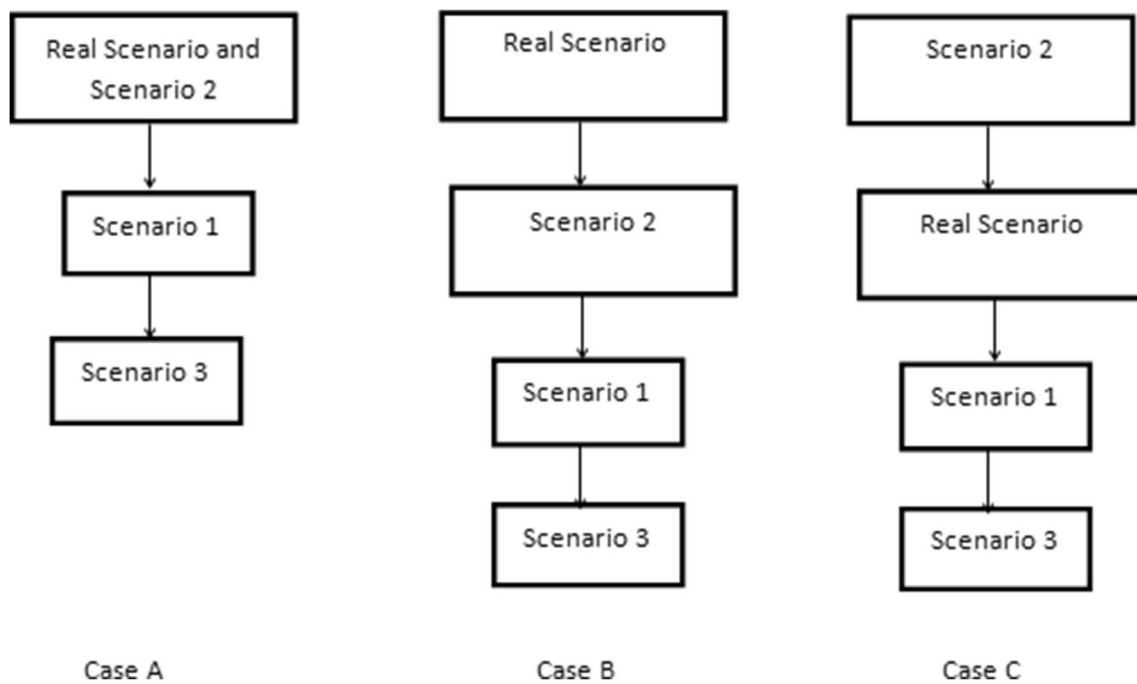


Fig. 12 The outranking of scenarios after changing thresholds of each criterion

- The threshold was not taken into account since no value tested has allowed to remarkably influence the rankings (INERIS 2005).
- For thresholds q and p , β constant is always nul because it is estimated that the error related to the data is proportionate for them (INERIS 2005).
- The initial values of these parameters are $\alpha = -0.15$ and $\beta = 0.3$.
- For each parameter, we start by searching its critical value, i.e., the maximum value / the minimum value which creates no change in the final result.

We aim to find out how changes in the weights would affect the ranking of the alternatives; equal values for criteria weights will be used in judging the sensitivity of the obtained solution. The value is set as 0.16. The outranking result is depicted in Fig. 11. Besides, we find out how the accuracy of the basic data is reflected in the order of the various alternatives; we change indifference threshold (q) and preference threshold (p), which results in values of α and β for three cases. The outranking result is depicted in Fig. 12.

Case A ($\alpha = \beta = 0$): We eliminate imprecision and margin of error in the data; the pseudo-criteria is transformed in real criteria.

Case B ($\alpha_q = 0.1$, $\alpha_p = 0.2$, and $\beta = 0$).

Case C ($\alpha_q = 0.2$, $\alpha_p = 0.5$, and $\beta = 0$).

- To verify the credibility degree of the results, we change the values of α and β for the distillation threshold as $\alpha = -0.15$ and $\beta = 0.3$ (the default values). The final ranking remains stable when the values are as follows:

Min $\alpha = 0$ and min $\beta = 0.17$: We estimate $S(\lambda) = 0 + 0.17\lambda$ being the minimum value of distillation threshold.

Max $\alpha = -0.3$ and max $\beta = 0.43$: We estimate $S(\lambda) = -0.3 + 0.43\lambda$ being the maximum value of distillation threshold.

Thus, the distillation threshold can change result only when with large variation.

Despite changing the values of α and β for three thresholds, scenario 2 seems to outperform scenarios 1 and 3 and the real scenario, which implies that the municipal solid waste collection and transport system for Elboustene borough, Sfax city, should be unloading waste in transfer station 2 being more advantageous than unloading in transfer station 1 or distributing to both transfer stations.

The outranking results for all cases were illustrated. It has been affirmed that scenario 2 is the best planning strategy for MSW collection in Elboustene, Sfax. In scenario 2, all the vehicles start their trips from the depot, collect garbage from the gather sites, and unload waste at transfer station 2, then go back to the depot. Using this strategy would improve the total distances and time for all the vehicles (155.2 km and 10.9 h,

respectively), which is better than those of the current scenario (166.75 km and 14.10 h, respectively). The results prove that there is no good in using the transfer station 1.

Conclusions

The aim of this paper is to analyze the MSW collection in the city of Sfax (Tunisia). Three feasible waste collection scenarios were proposed and have gained the consensus of decision makers and stakeholders. A GIS-based multi-criteria approach is developed to identify the most appropriate scenario. A sensitivity analysis is performed to assess the robustness of the results and has confirmed scenario 2 to outrank the others. For this scenario, all vehicles start their trips from the depot, collect garbage from the gather sites, and unload waste at transfer station 2 then travel back to the depot. Using this scenario would achieve a total distance of 155.2 km and a total time of vehicle use of 10.9 h which are, indeed, better than those of the scenario currently running (total distance traveled 166.75 km, total time vehicle use 14.10 h). This scenario is characterized by more environmentally friendly practices and increased effectiveness. The findings are significant for the planning and management of municipal solid waste in the city and would, definitely, help overcome the environmental challenges that the city is currently facing.

The proposed methodology could easily be implemented in similar MSW collection contexts where a finite number of feasible scenarios could be generated. A successful implementation requires, on the first hand, the involvement of municipal decision makers in adopting multi-criteria decision aid approach and, on the other hand, the consensus of other stakeholders.

Compliance with ethical standards This research does not involve any human or animal participation. All authors have checked and agreed the submission.

Conflict of interest The authors declare that they have no conflict of interest.

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