

## Optimization of Household Waste Collection Routes Using GIS: Case Study El Bousten district, commune of Sfax, Tunisia

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### ABSTRACT

This paper presents a method for optimizing the household waste collection system supported by Geographical Information System (GIS) tool for the sector 1 of district El Bousten of Sfax commune, Tunisia. The ArcGIS Network Analyst based model is applied for the purpose of improving the collection process effectiveness, namely, the household collection bins' reallocation along with the vehicles' tour optimization procedure in terms of distance and time. Results indicated a reduction of 25, 83% in route and 21, 5 % in the time spent of collection along with fuel consumption savings. These findings show that GIS based model tends to exhibit significant improvements as to the collection and transportation system, therefore, to its economical and environmental costs.

**Keywords:** Household waste collection, Geographical Information System, Network Analyst, El Bousten district, reallocation.

### INTRODUCTION

Waste management is a global environment issue, which constitutes a very significant problem in today's world. Since improper waste management places inhabitants at risk, urban waste management is presently receiving greater attention from municipalities in developed and developing countries because of its impact on public concern for the environment<sup>1,2-3</sup>. There is a considerable amount of waste disposal without proper segregation, which is leading to both economic and environmental problems. The collection and transport of household wastes are among the most important factors in the management of wastes, hence representing a major part of the budget. Consequently, it is essential for a lasting management to reduce in the first hand the impact on the environment and on the other hand to minimize the cost of collection and transport. For this purpose, one must have reliable elements for

optimizing the circuits of collection, which show the most common difficulties in this type of management<sup>4</sup>.

In this respect, the Geographic Information System (GIS) invention turns out to offer a highly innovative modeling option, allowing the decision takers to investigate or devise a wide range of the waste managing related issues. Indeed, integration of GIS technology with solid waste management has been recognized as one of the most promising approach to automate the process of planning and better management of solid waste management<sup>5-6</sup>. Optimization of waste collection and transportation making use of the novel tools offered by spatial modeling techniques and GIS may provide large economic and environmental savings through the reduction of travel time, distance, fuel consumption and pollutants emissions<sup>7, 8,9,10,11,12</sup>.

In this regard, several works applied the GIS for general studies of vehicle traffic (Ericsson et al., 2006; Taylor et al., 2000)<sup>13-14</sup> or to the wastes collection, the deposit point of containers and the vehicle routing (Apaydin and Gönüllü, 2008<sup>15</sup>; Ghose et al., 2006<sup>16</sup>; Jovièæ et al., 2011<sup>17</sup>; Karamidas et al., 2008<sup>5</sup>; Lakshumi et al., 2006<sup>18</sup>; Tarantilis et al., 2004<sup>19</sup>; Tavares et al., 2009<sup>12</sup>; Teixeira et al., 2014;<sup>20</sup> Zamorano et al., 2009<sup>21</sup>; Zsigraiova et al., 2009, 2013<sup>22-23</sup>). The problem of vehicle routing is a common one: each vehicle must travel in the study area and visit all the waste bins, in a way that minimizes the total travel cost: most often distance or time but also fuel consumption, CO2 emissions etc. (Chalkias and Lasaridi, 2011<sup>24</sup>).

With regard to the Tunisian context, expenditure on garbage collection and transport constitutes 75% of the total solid waste management budget, most of which is spent on payrolls salaries and fuel. Noteworthy, however, is that the present collection process has always been undertaken in an indiscriminate and irrational manner, manely with regard to the jurisdiction of the Sfax city municipality. As a matter of fact, the household waste collection

vehicles are usually assigned to operate in several areas without any seriously elaborated demand analysis study, with the route itinerary being left to the truck drivers themselves. Such a state has often engendered remarkably high solid waste collection costs.

This research is conducted with the purpose of optimizing the household waste collecting routs in terms of distance and time at the comprehensive waste management. The Network Analysis toolbox of the ArcGIS software is utilized to evaluate the optimal waste collection routes.

## MATERIALS AND METHODS

### Case study area and current status of the collection system

Covering an area of 325 acres and 15707 inhabitants, the El Bousten district is selected as a case study with regard to the present work. The district El Bousten, stands as one of the most important districts of the commune of Sfax, englobing 7 districts: El Medina, Sidi Mansour, Sfax Nord, Errbadh, Merkez Chaker, Cite El Habib and El

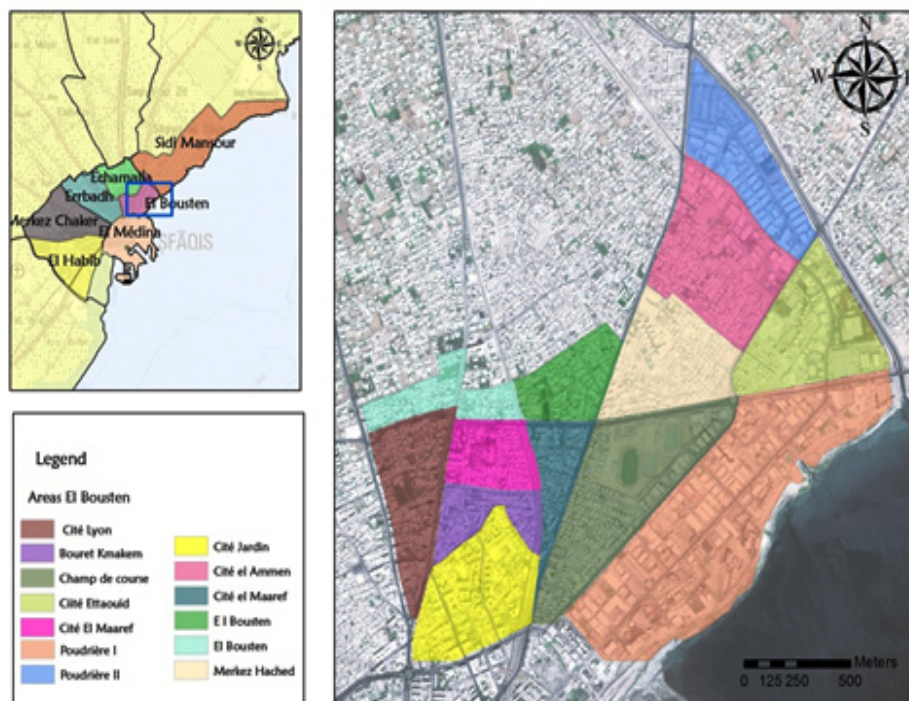


Fig.1: Location of district El Bousten as study area

Bousten (Fig. 1). It is actually a very representative area as it covers a large number of residential buildings, offices, shops and restaurants, as well as a faculty and students' dormitory. The privately owned company of Mohamed Ben Saad is responsible for annually collecting and transporting 7000 tons of household garbage wastes and rubbish, i.e., 1.25 kg/ capita. The generated solid waste is transported by means of 2 compaction vehicles of 16m<sup>3</sup> capacity along with 2 tractors of 5m<sup>3</sup> capacity for disposal in the transfer station, 17 km away from the depot.

The collection timing program is daily executed from 9:00 am to 3 pm, and waste collection is carried out manually and mechanically. The collection transportation cost relevant to the district El Bousten is 41 TND/t. Empirically, and to facilitate the operation procedure, the district is divided into three sectors, with a frequent collection and transportation undertaken over seven days of the week. The study area, subject of the present study, belongs to sector 1, and the examined area covers about 0.75 km<sup>2</sup>, with a population exceeding 8841 citizens and a waste generation rate of about 10,300 tons per day, according to the collection

vehicles' weighing sheets over the year 2012. The actual waste collection process is performed at street and household residential dwelling level, using compacting truck and two hand-pushed carts. In this sector, the waste collection is entirely allotted to the vehicle driver, engendering immense losses being recorded in matters of time amount and distance traveled, therefore, increased operational costs. Several studies conducted by researchers reveal well that itineraries being left to the truck drivers' experiences do not necessary signify that best routes are actually pursued. Currently, the private company's applied system appears to be inaccurately improvised, unscientific, outdated and inefficient. With solid waste being littered wherever possible, the private company does not seem to have adequate provisions to effectively deal with the ever-growing problem of solid waste management. Indeed, no effort has been made to store waste at the selection source site, much less no norm is being undertaken on setting the bins' capacity and placement, resulting in some bins/pits remaining overflow. Given such noticeable defects observed to prevail within the existing waste management, a special methodology relevant to adequate the

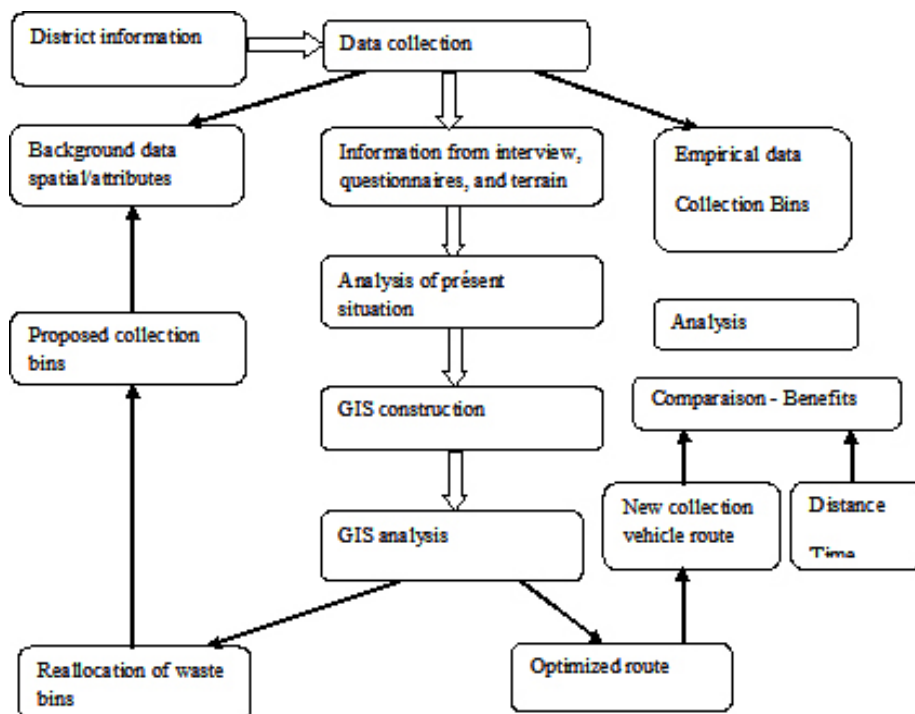


Fig. 2: Flow chart showing GIS analysis for household

household waste collection and transportation procedure seem imposed, as based on the GIS model devised process.

## METHODOLOGY

By relying on GIS, the collection system optimization approach turns out to stand as an effective means, whereby spatial data can be imported, managed, and analyzed. The present work's pursued methodology consists of three major stages, namely (Figure 2):

- Data collection
- Spatial Database development
- GIS Analyses: ArcGIS NA

### Data collection

In cooperation with the Sfax municipality and nomena fieldwork, the following data have been gathered and processed in suitable forms (vectors, tables, and raster): delimitation of the study area; detailed land use plan of the municipality; population distribution and density; satellite image (Google Earth); road network; and information on roads (traffic, restrictions, and signs). The collection route has been tracked via a GPS (Global Positioning System) to extract all the relevant data and facts: coordinates of collection points, from parking (starting point/circuit end) and from landfill; the capacity and the vehicles' number and capacity as used in the collection; the route of each vehicle, number of workers, condition of waste on site, condition of container and bins, odometer reading before departure and after collection time. Certain background spatial data were taken from the municipality of Sfax. It concerns road network, existing routes, bins and building parcels. All data are restructured with field work as well as non spatial data for instance road name, road type, vehicle average speed, travel time, road slope, bin number, bin type/capacity, bin collection time are added. The collected information is then stored in a spatial database.

### Spatial Database development

The geodatabase was constructed using the GIS environment of ArcGIS (ESRI). The main sources of the spatial database (SDB) are urban development plan, maps digitized in ArcGis10.1,

satellite images (Google Earth), municipal and statistical services data, data derived from field work and literature data and the company responsible for the waste collection service. These data are geodetically corrected into the Lambert Conic Conform Projection System. Once the database is established, an optimization model is performed through application of the Network Analyst (NA) tool on ArcGIS.

### GIS Analyses: ArcGIS NA

The Network Analyst extension of ESRI ArcGIS was used in this study to recommend optimization of the route. It is a powerful extension that helps providing network-based spatial processing involving routing, travel directions, closest facility, and service area analyses. The Network Analyst extension allows users to represent real network conditions and resolve vehicle routing problems that incorporate turn limitations, speed limits, elevation restrictions, and travel conditions.

With the ability to help in finding the shortest route through all containers for waste collection, while simply showing their locations. After setting the stop points, the optimized routes for the solid waste collection were produced. The sequence of stoppages to be visited was defined via Network Analyst. It includes a cost reduction option (the impedance) to be derived during the calculation of the best route. So, the most optimum path can be determined as that with the shortest circuit and therefore, costs the least, with the itinerary being selected by the user himself. As far as the present work is conceived, using Network Analyst to define an optimum path fit for the waste collection process is generated with respect to the area subject of study.

## RESULTS AND DISCUSSION

The above mentioned approach has been used in our context for the purpose of examining the household garbage collection method with the jurisdiction of the Sfax municipality. Actually, two different undertakings or procedures are being considered at this level namely the waste bins reallocation as well as an optimal route analysis using the nearly proposed bins sites.

**Reallocation of the household collection bins**

According to the statuesque situation, a total of 28 collection bins are placed in sector 1 of the district El Bousten, with holding capacities of 360l, with no norm has been followed to allocate these bins. For the sake of further to improving the existent collection system in the ward, the insufficiency related to the waste collecting containers and their service areas is reconsidered. Adding an additional tray is required for each tray overflowing.

We proceed to the reallocation of these bins in the study sector according to the following criteria:

- Allocating bins wherever open dumps are persistent
- Installing new bins next to existing bins' locations
- Allowing the installation of several bins per every single crossing.

In a stage, the essential number of waste bins to be placed was assessed according to the daily and weekly waste quantities generated in the sector 1 along with the suggestion to substitute the

small bins with larger ones of 770 l capacity. This procedure is given by equation (1) as follows:

$$N = \frac{W}{D * S * F1 * CF} \dots(1)$$

Where

N = Number of bins

W = Total quantity of waste generated per day in Kg

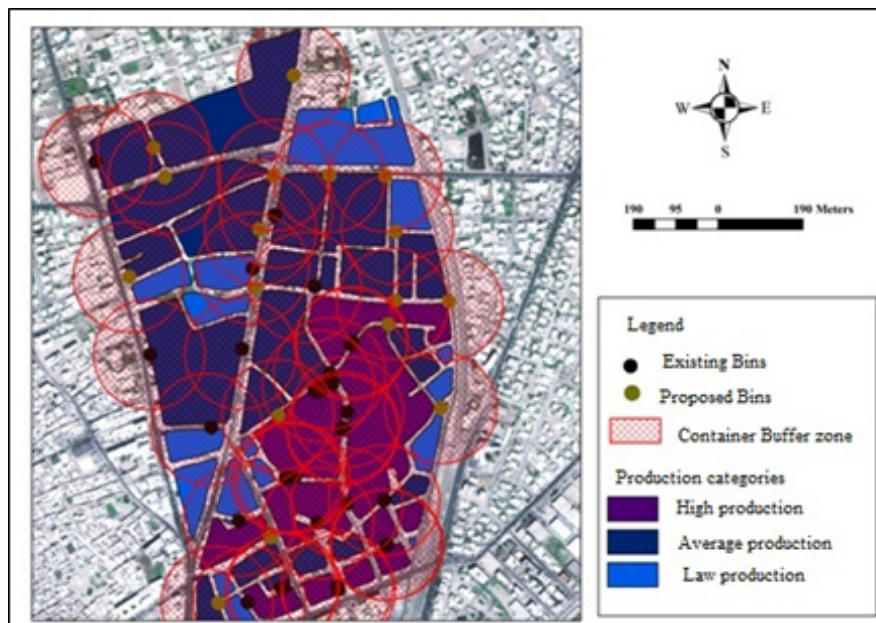
D = Average density of household waste in Kg m<sup>-3</sup>

S = Bin capacity in m<sup>3</sup>

F1 = Coefficient of filling the bin (considered 80% in the present study)

CF = Collection Frequency

Hence, a need for 18 extra appears to persist as a solution bins to absorb the excessively overflowing bins, in considering an average waste density of 0.4 t/m<sup>3</sup> and 0.77m<sup>3</sup>capacity containers. It has been noted that most of the circuit containers have a volume of 0, 36 m<sup>3</sup> while the minor part is formed by containers of a smaller volume of 0, 75 m<sup>3</sup>. This number is assumed to adequately suffice by suggesting to locate containers in sites which might



**Fig. 3: Reallocation of waste collection bins**



**Fig. 4: Optimized route after reallocating bins**

serve the entire population. Bins' redistribution is performed according to the distance separating them from dwellings, with the aim of increasing the bins' number. Thus, the longest distance to be traveled would not exceed 125 meters from the residential areas. The total area of sector 1 is covered by 46 bins of 0.75m<sup>3</sup>. Figure 3 highlights the redistribution of the waste bins throughout the sector.

#### **Optimal Routing**

Following the waste bins' redistribution, we proceed to optimizing the collection vehicle's routing. Figure 4 shows the proposed bins as collecting points and the possible shortest route. Route optimized by using the software was compared with present route.

The comparison results are presented in Table 1. According to the Table1, the optimal route corresponds to 8.9 km that the collection vehicle could traveled, as compared to 12 km currently traveled. This is 25.83% amelioration in respect of the current routing. Such a progress appears to be pronounced with the respect to the optimal routing travel time amount. Routing total travel time is calculated as time spent by the collection vehicle added to the bins' collection time. Global timing with

respect to the optimal itinerary is 211 minutes as a substitute of 269 minutes relevant the previously undertaken existing route (i.e. 21.5 % gains in the total collection time).

Given the fact that gasoline consumption and pollutant emissions are strongly related to the collection time span, selecting a conveniently appropriate itinerary path should certainly yield a great deal of fuel gains and emissions reductions. Moreover, in the proposed scenario, waste collection is proves to be entirely mechanized, thus removing the employ of collectors with pushcarts. This procedure is likely to yield cause additional economic gain for the municipality authority and help improve of the workers' health and protection environment. This provided labor can well workers in other tasks relating to the garbage management process, as street cleansing. Thus, the study has also been able to provide greater vision, insight, and repair scope concerning the presently undertaken collection route. In this way, the optimization attempts offered by this model study would certainly serve a great deal the local waste management by helping and offering them a precious opportunity to put things right and repair what might be repaired within the suitable time scope.

**Table 1: Comparison of the current route and the optimized route**

Route	Route Distance km	Route Time min	Improvement From empirical route %Distance(time)	Fuel consumption (l)	Number of collected bins	Workers
Current Route	12	269	-	19	28	5
Optimized Route	8.9	211	25.83 ( 21.5)	14	46	3

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