A GIS based model for the optimisation of municipal solid waste collection: the case study of Nikea, Athens, Greece

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Abstract: Waste collection and transport (WC&T) constitutes a large fraction of the total municipal solid waste (MSW) management costs worldwide. In Greece currently this may account for 70-100% of the total MSW costs, most of it being spent on salaries and fuel. It is therefore crucial to improve the WC&T system through routing optimisation. Geographic Information System (GIS) technology provides an advanced modelling framework for decision makers in order to analyse and simulate various spatial waste management problems, including waste collection. In this study a methodology for the optimisation of the waste collection and transport system, based on GIS, was developed. A model in ArcGIS Network Analyst was developed in order to improve the efficiency of WC&T in the Municipality of Nikea (MoN), Athens, Greece via the reallocation of waste collection bins and the optimisation of vehicle routing in terms of distance and time travelled. Two scenarios were compared with the current empirical collection scheme: S1-collection vehicle routing optimisation, and S2-reallocation of bins and routing optimisation. Results demonstrate that both scenarios provided savings compared to the current situation in terms of collection time (3.0% and 17.0% for S1 and S2 respectively) and travel distance (5.5% and 12.5% for S1 and S2 respectively). Time and distance reduction relate to similar CO_2 emissions and fuel consumption savings. These figures indicate that GIS based models can offer significant improvements to the WC&T system and, consequently, to its financial and environmental costs.

Key-Words: municipal solid waste (MSW), waste collection, GIS, Network Analyst, routing, route optimisation, modelling.

1 Introduction

The new Paradigm for sustainable solid waste management, as it stems from the need for resources conservation and is best expressed in the EU policy (e.g. new Waste Framework Directive 2008/98/EC, Landfill Directive 99/31/EC) requires that waste is source separated and treated to recover materials and energy prior to disposal. Specific recycling, recovery and landfill diversion targets are set for various waste streams, such as packaging waste, biodegradables, construction and demolition waste, used tyres, electrical and electronic waste, etc. This increased level of service will need to be provided at the minimum possible cost, as the public will not be able to bear large increases in its waste charges.

Therefore, the sector of waste collection and transport (WC&T) attracts particular interest regarding its potential for service optimization as: (a) waste management systems with more recyclables' streams usually require more transport [1]; and (b) this sector already absorbs a disproportionably large fraction of the municipal budget available to waste management [2].

Local Authorities (LAs) constitute worldwide the main providers of municipal solid waste (MSW) management services, either directly or indirectly, through subcontracting part or all of these services. In the EU states, LAs are therefore under increasing pressure to improve the level of service provided while keeping costs low.

Service optimisation, both in terms of quality and costs can only be achieved using advanced decision support tools, modelling the many different components of an integrated waste management system [3-5]. Geographic Information Systems (GIS) have been proved an efficient technology for analysing complex spatial phenomena. They have been successfully used in a wide variety of applications, such as urban utilities planning, transportation, natural resources protection and management, health sciences, forestry, geology, natural disasters prevention and relief, and various aspects of environmental modelling and engineering [6-10]. Among them, the study of complex waste management systems, in particular sitting waste management and disposal facilities and optimising WC&T, have been a preferential field of GIS applications, from the early onset of the technology [1, 11-15].

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 minimises the total travel cost: most often distance or time but also fuel consumption, CO_2 emissions etc. This is very similar to the classic Travelling Salesman Problem (TSP) [16]. However, as Karadimas et al. [14] pointed out, the problem of optimising routing aspects of solid waste collection networks is an 'asymmetric TSP (ATSP) due to road network restrictions'.

As the success of the decision making process depends largely on the quantity and quality of information that is made available to the decision makers, the use of GIS modelling as a support tool has grown in recent years, due to both technology maturation and increase of the quantity and complexity of spatial information handled [17]. In this context, several authors have investigated route optimisation, regarding both waste collection in urban and rural environments and transport minimisation, through improved sitting of transfer stations [11], landfills [18] and treatment installations in the context of integrated regional waste management [19-21].

Optimization of WC&T making use of the novel tools offered by spatial modelling techniques and GIS may provide large economic and environmental savings through the reduction of travel time, distance, fuel consumption and pollutants emissions [5], [20], [22 – 25]. These systems are particularly rare in Greek local authorities, where WC&T is typically organised empirically and in some cases irrationally, under public pressures [14, 26, 27].

According to Tavares et al. [5] "effective decision making in the field of management systems requires the implementation of vehicle routing techniques capable of taking advantage of new technologies such as the geographic information systems". Using GIS 3D modelling in the island of Santo Antao, Republic of Cape Verde, an area with intense relief, they achieved up to 52% fuel savings compared to the shortest distance, even travelling a 34% longer distance. Nevertheless, most of the previous work relating to optimal routing for solid waste collection is based on the minimisation of the travelled distance and/or time [28, 29], which is considered a sufficient calculator parameter for fuel consumption and emissions minimisation in flat relief [30].

In the case studies of routing optimisation reported in the literature both commercial waste routing software and especially developed models based on ArcGIS® Network Analyst are reported. Apaydin and Gonullu [28] utilised RouteViewPro™ to achieve a 24.6% reduction in distance and 44.3% in total time travelled in the city of Trabzon, Turkey. Using WasteRoute a 10% reduction in the number of collection trips was achieved in the area of Elgin, Illinois, USA [25]. Ghose et al. [12], on the other hand, used ArcGIS® Network Analyst to successfully minimise the distance and cost of waste transportation to landfill in the city of Ansasol, India.

In Greece LAs are by law responsible for waste management (Decrees 25/1975 and 429/1976). Especially waste collection and transport are provided at the individual municipality level, usually directly through their Waste Management Department. Currently, WC&T of commingled MSW in the country is responsible for a large portion of the total waste management costs, in the range of 70-100% [2, 14]. This is considerably higher than the typical values, of between 50 and 75%, reported for modern waste management systems [1] because the largest fraction of the waste stream is landfilled at very low cost without any pre-treatment for materials and/or energy recovery, while in some cases illegal dumping may be still practiced [31].

The aim of this work was to develop a methodology for the optimisation of the waste collection system, based on GIS technology. The methodology was applied to the Municipality of Nikea (MoN), Athens, Greece, based on real field data. The strategy consisted of replacing and reallocating the waste collection bins as well as rescheduling waste collection via GIS routing optimisation. The benefits of the proposed strategy were assessed in terms of minimising collection time, distance travelled and man-effort, and, consequently, financial and environmental costs of the collection system.

2 The Municipality of Nikea and its waste collection scheme

2.1. Geographic and demographic aspects

The commingled MSW collection system of the Municipality of Nikea was selected as a case study. The MoN (Fig. 1) is one of the largest in the Attica Region, lying in the SW part of Athens metropolitan area. It has a permanent population of 95,798 habitants according to the 2001 Census (National Statistical Service of Greece - NSSG, 2001) and a total area of 6.65 km^2. Nikea is a typical Greek urban municipality, characterised by multi-storey apartment buildings, combined by lower multiple dwellings (2-4 apartments) and mixed residential and commercial land uses in many neighbourhoods.

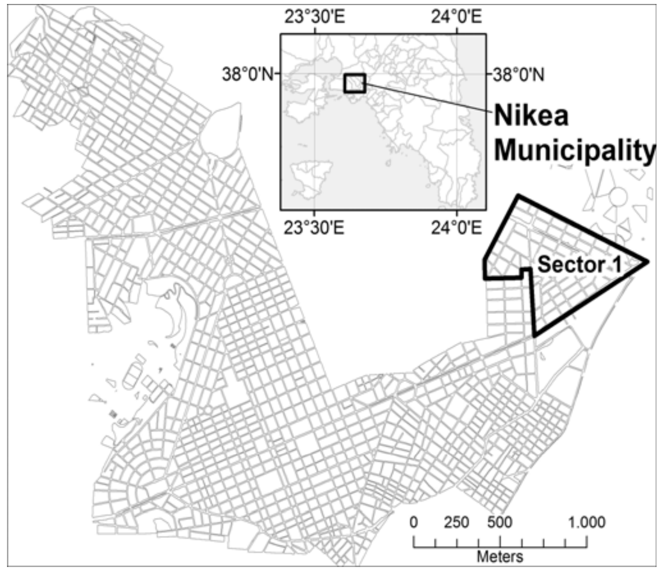

Fig. 1: The case study area: Municipality of Nikea.

2.2 Waste collection in the Municipality of Nikea

The annual MSW production in MoN is estimated at 45,625 tn, or 1.30 kg/ca/d. Waste collection is carried out mechanically, using 12,000 wheelie bins and 17 rear-end loaded compaction trucks with 9 tn average capacity (10 vehicles of 8-9 tn, 4 of 9-10.5 tn, 2 of 6-7.5 tn and 1 of 4-5.5 tn). The crew size on the vehicle is three persons, a driver who never leaves the truck (as required by safety regulations) and two workers who move and align the bins with the hydraulic lifting mechanism of the truck.

The Municipality is empirically divided into 15 sectors (collection zones), each of which is further divided into two sub-sectors. Waste is collected in each sub-sector every other day. Most of the bins are small, of 120 and 240 L capacity, but a few larger ones exist in some central points. In total there are currently 12,107 bins in MoN, of which 875 of 120 L, 9526 of 240 L, 504 of 330 L, 1110 of 660 L and 92 of 1200 L [32].

The peculiarity of the Nikea waste collection system is that, although supposedly mechanised, the large number of small bins makes full mechanical collection infeasible. Therefore, to the aforementioned crew of three persons per truck, another worker is added, starting his shift about half an hour earlier from the collection vehicle.

This worker either moves small bins from their location to central points and crossroads, from where they will be mechanically collected, or manually empties the content of bins with low load to other more central ones, which in turn are mechanically collected. In total, it is estimated that only 70% of the bins are mechanically collected, with the content of the rest being manually transferred in other bins. The worker going ahead on foot and the two workers on the vehicle perform their duties in rotation.

This work applies the developed WC&T optimisation methodology in one of the collection sectors of Nikea, Sector 1 (Fig. 1) a typical sector with mainly residential land use. Nevertheless, commercial establishments, schools, stadiums and parks are also found in the area, which is divided by a major avenue (Petrou Ralli). The served *equivalent* population in Sector 1 (i.e. taking into account the MSW load created by non-residential land uses) is 6,790 people, divided in 63 parcels (building blocks). The total average waste production is 2,610 tn/yr according to the weighing sheets of the collection vehicles in the period 2005-2007. This corresponds to an average daily commingled waste production of 1.053 kg/ca *eq*.

In the current waste collection system, 714 bins are located in Sector 1, of which 501 are mechanically collected, as follows: 390 bins of 240 L, 41 bins of 330 L, 62 bins of 660 L and 8 bins of 1200 L [32]. The content of the rest is manually transferred to the mechanically collected ones by the worker walking ahead of the collection truck. Since Sector 1 is rather flat (mean elevation ~ 50 m) it is assumed that fuel consumption and emissions are linearly related to collection time [1, 30].

For waste collection purposes, Sector 1 is divided into two sub-sectors (Fig. 2), both served by one waste collection vehicle. Waste in each sub-sector is collected four times per week, in alternate week days, resulting into eight collection trips per week. Collected waste is disposed of at the Fyli landfill site, about 30 km north-west from Sector 1.

Nikea municipality has recently introduced a dry recyclables collection scheme, targeting packaging waste and printed paper. This is a door-to-door single-stream recyclables collection system, in which all recyclables are collected together in one bin, also known as the blue bin system. The blue bin is separately collected once per week by a separate vehicle and materials are transported to a Materials Recycling Facility (MRF) where they are mechanically and manually separated into different streams and directed to the markets. The recyclables collection scheme was simply added to the existing commingled waste collection, without re-adjusting the existing collection trips.

Although the targeted waste by the blue bin system constitute a substantial fraction of the total waste stream, about 40% for Greece, the system is not fully developed yet and does not cover all the population of the municipality. This fact, in combination with a yearly increase of the total waste quantity produced by about 3% (the national average [31]) has led to a continuing exploitation of the full capacity of the existing commingled waste collection system. However, a better development of the recycling system in the future will require a restructuring of both collection systems in order to minimise costs and optimise waste collection resources [1].

In this study, the objective of the developed system was to identify the optimum scenario for waste collection of commingled waste, in terms of minimising collection time, distance travelled and man-effort, and consequently financial and environmental costs. A key point to this approach was the replacement of the existing large number of small bins (120 and 240 L) with a reduced number of larger bins (1100 L). Using the collected data and the analytical tools of the GIS software specific proposals are developed regarding (a) the optimisation of the existing WC&T system of commingled MSW, and (b) its adaptation to the new legislative demands regarding packaging and biodegradable waste.

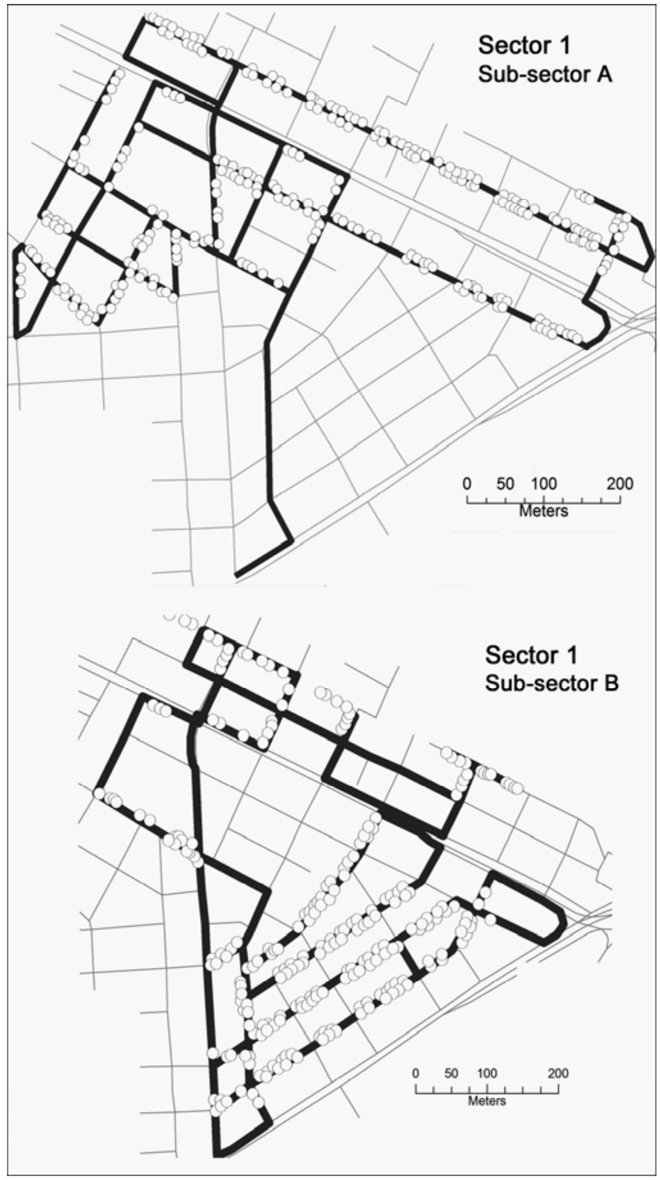

Fig. 2: Current empirical MSW collection scheme.

Finally, the results of the proposed systems are compared with the empirical method currently used by the Municipality of Nikea. Only the vehicle trip within the sector is considered for the optimisation, not taking into account the travel to and from the landfill.

3 Data collection and description

In order to efficiently manage the municipal solid waste system, detailed spatial information is required. This information is related to the geographical background of the area under investigation as well as to special data related to the waste collection procedure.

In co-operation with the municipality a large database of waste management data for the period 1998-2007 has been collected and statistically analysed, regarding the static and dynamic data of each existing collection program: population density; waste generation rate for mixed waste and for specific waste streams; number, type and positions of waste bins; the road network and the related traffic; the current routing system of the collection vehicles; truck capacities and their characteristics; and, the geographic boarders and characteristics of the waste collection sectors. Thus, for the optimisation of the collection process the following data were generated (data source in the bracket):

- Study area boundary (Municipality Corporation)
- Detailed urban plan of the municipality (official toposheet plan)
- Population density distribution (NSSG)
- Land use of the study area (NSSG)
- Satellite image of the municipality (Google Earth)
- Road network of the study area (official toposheet plan)
- Road class information: restrictions and traffic volume details (official toposheet plan, Municipality Corporation)
- Location of waste bins (Municipality Corporation, field work)
- Capacities of bins (Municipality Corporation)
- Time schedule for the collection process (Municipality Corporation)
- Existing collection routes (Municipality Corporation)
- Vehicle speed, fuel consumption, CO_2 emissions of the compactors (Municipality Corporation, field work, literature).

For the optimisation of the collection process a spatial geodatabase was designed and implemented, using a standard commercial GIS environment (ESRI, ArcGIS). This choice ensures compatibility with the available data from Nikea municipality and access to many network analysis routines available from the software. The content of the spatial database (georeferenced in the official Greek reference system - HGSR 87) is summarised in Table 1.

Background spatial data for road network, existing routes, bins and building parcels were obtained from MoN. These data were updated with field work and other non spatial data such as road name, road type, vehicle average speed, travel time, road slope, bin number, bin type/capacity, bin collection time are added. Furthermore, special attributes of road network were registered. These attributes included traffic rules, traffic marks, topological conditions and special restrictions (e.g. turn restrictions) in order to model efficiently the real world road network conditions.

Table 1: The spatial database - type of data and corresponding geometry.

Spatial Data	Type	Geometry
Road network	vector	Line
Waste bins	vector	Point
Urban plan / parcels	vector	polygon
Existing run routes	vector	Line
Street address	tabular	-
Road network attributes / restrictions	tabular	-
Waste bins' attributes	tabular	-
Population data	tabular	-
Land use data	tabular	-
Satellite image of the MoN	Raster	-

4 Methodology

The key point of the proposed analysis is GIS technology. GIS provides an effective mean to import, manage and analyse spatially based data. The methodology used in this work comprised of three general steps (Fig. 3). Step 1 establishes the spatial database of the study area as described previously. Step 2 is dedicated on the reallocation of waste collection bins with the use of GIS spatial analysis functions. Finally, Step 3 consists of the waste collection routing optimisation for minimum time, distance, fuel consumption and gas emissions. The waste collection optimisation model was developed with the use of ArcGIS 9.2 Network Analyst (NA) GIS software.

4.1 Spatial Database (SDB) development

In order to analyse the spatial data for the optimisation of the waste collection scheme in MoN, a spatial database (SDB), within a GIS framework, was constructed. The description of this database is provided in the previous section of this paper. The main sources of the SDB are (a) analogue maps from MoN, (b) digital data from various official providers (e.g. National Statistical Service) (c) data derived from field work / on-site data capture with the use of GPS technology.

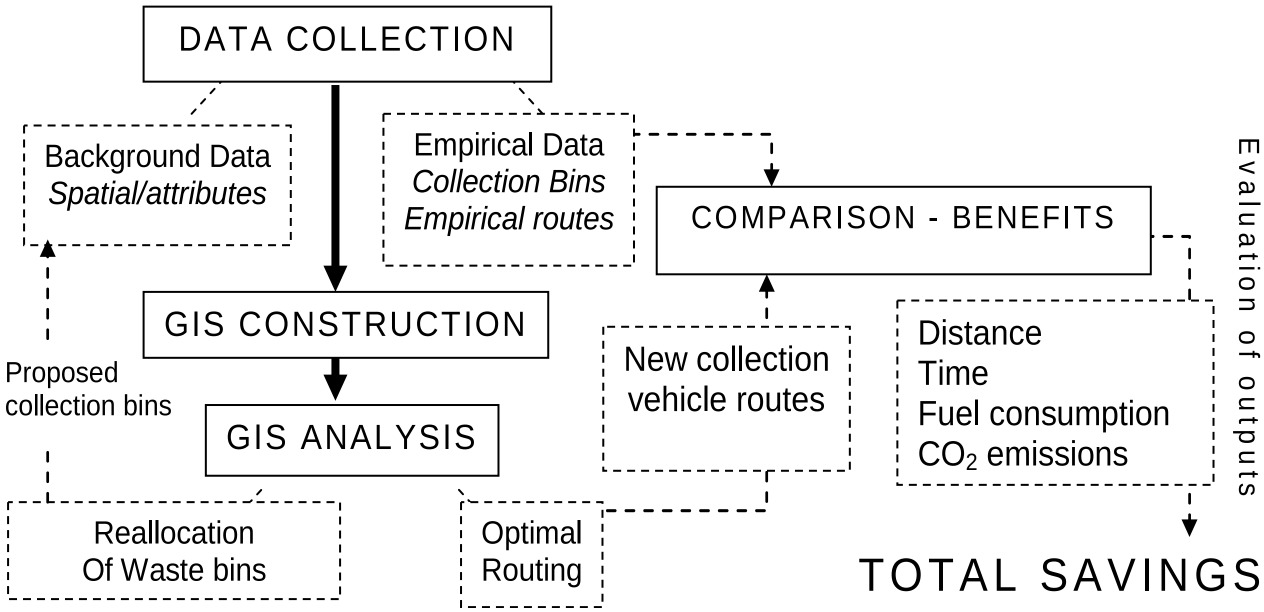

Fig. 3: Data flow of the proposed methodology

4.2 Reallocation of waste collection bins

The next phase of the proposed methodology is related to the reallocation of waste collection bins. This analysis was implemented in a GIS environment with the use of sophisticated spatial analysis functions. The placement of the waste collection bins in their newly proposed positions was based on the following criteria / restrictions:

First, the number of required bins was determined, on the basis of the daily and weekly produced waste quantity in Sector 1 and the decision to replace small bins with larger of 1100 L capacity [32]. Thus, instead of the existing 501 bins of various sizes the installation of 162 bins of 1100 L capacity is proposed. This number was calculated as not to allow for any overflow of the bins system during the whole week, while it also allows for a 10% safety capacity. This was considered particularly important in order to avoid potential opposition of the residents to the change of the collection system.

Next, the allocation of these bins in the study area was performed according to the following rules: a) allocate bins on the road network (intersections are preferable); b) install new bins near existing bin locations (in a buffer zone 60 m wide); and c) allow the placement of more than one bin at the same intersection. The number of the bins sharing the same intersection point is related to the surrounding land use and the population of the covered area.

4.3 Routing – Network analysis

After the reallocation of the waste collection bins the optimisation of waste collection vehicle routing was performed. For this purpose, the ArcGIS NA modelling package was utilised. The optimal path finding algorithm of NA is an alteration of the classic Dijkstra's algorithm [33] which solves the problem of optimal route selection on an undirected, nonnegative weighted graph in a reasonable computational time [34]. In the literature, many modifications and new algorithms have been used for the incorporation of these aforementioned restrictions (among others) [35-37]. In the context of ArcGIS Network Analyst commercial GIS software, this algorithm is improved further by using effective data structures such as d-heaps [38]. To use it within the context of real transportation data, this algorithm must be modified in order to respect real problem restrictions, such as one-way roads, prohibited turns (e.g. U-turns), demand at intersections (nodes) and along the roads, and side-of-street constraints while minimising a user-specified cost attribute.

The main idea is to build a cost matrix containing the costs between origins and destinations. These points correspond to pairs of vehicle stops (waste bins). The total travel time for the optimal route is the sum of the travel time for each road segment plus the collection time for the waste collection bins.

The user of ArcGIS NA is able to define all the traffic conditions defined above, the stop delay for each waste collection bin and the first and last collection stop. The final output is an optimal solution in terms of distance or time criteria.

5 Results and Discussion

The method described above was applied to analyse the waste collection scheme of the municipality of Nikea, Athens Greece. Two different optimisation approaches were considered: 1) the improvement of the temporary storage system, through the replacement of the large number of small bins with a smaller number of large bins and their reallocation as to facilitate their collection; and, 2) the optimal route analysis with the developed GIS model, using the proposed bins as stops.

The reallocation of bins is based on travel distance (from each residence to the nearest bin) and the general intention to decrease the total number of bins. Thus, a maximum travel distance of 60 meters from each resident to the proposed new site of the bin was allowed. Moreover, the introduction of new bins with larger capacity, to accommodate for the same waste quantity, ensures the decrease of the total number of bins and collection stops. As a result a total of 162 bins in new proposed locations replaced the existing 501 bins in Sector 1. Fig. 4 illustrates the proposed reallocation of waste bins in the sector under investigation. A higher priority for the allocation of the new bins was given to locations of bins in the existing system and to crossroads in order to facilitate social acceptance and collection vehicle travel.

Based on various criteria and restrictions adopted in ArcGIS Network Analyst, different routing solutions were created. The routing solutions are generated with the use of a heuristic approach (Dijkstra's algorithm). This approach is taking into consideration the location of 162 new larger bins.

In order to evaluate the outputs of the proposed methodology two different waste collection scenarios were examined and their results were compared with the measured data of the existing collection scheme (Scenario 0), as follows (Table 2).

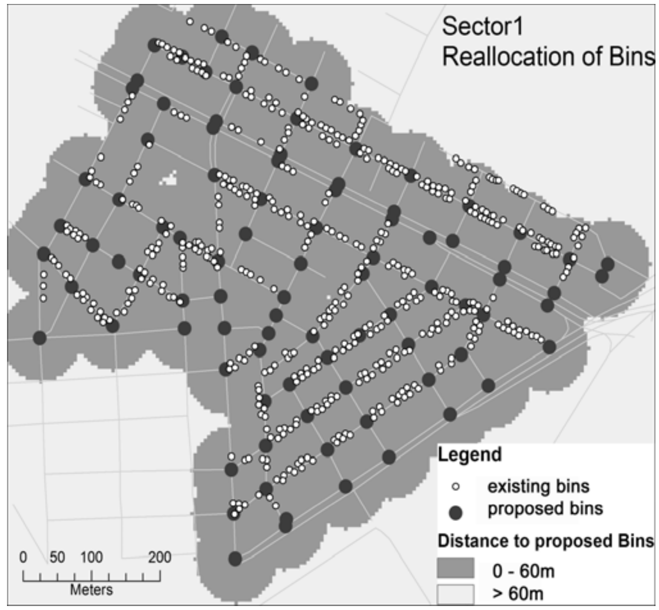

Fig. 4: Reallocation of waste collection bins

Scenario 0: The current empirical waste collection scheme.

Scenario 1 (routing optimisation on S0): A waste collection scheme using route optimisation for the existing waste collection bins.

Scenario 2 (reallocation of bins and routing optimisation): A waste collection scheme introducing different types and reallocation of bins with route optimisation.

The time needed during waste collection has three distinct components: 1) time for hauling; this is not taken into consideration in this study, as it is not affected by the proposed system re-organisation for each individual collection trip; 2) time for driving during collection; and 3) time for emptying the bins [1]. In this study only component 2 and 3 were considered.

Model tuning was based on real data provided by the Municipality of Nikea and verified by field study. According to these, the time for emptying the bins (bin loading, emptying and unloading – component 3) is 30 sec for bins with capacity up to 330 L and 60 sec for bins with capacity equal to or larger than 660 L. The time for driving during collection (component 2) is determined by the average speed of the collection vehicle in the travel between stops and the total distance traveled in the collection segment of the route. For MoN the average speed is 5, 10 and 15 km/hr for 1-way, 2-way and central roads, respectively.

Both parameters are not readily available and default literature values are scarce. Sonesson [1] reports on values on time for bin emptying from empirical data for the wider Uppsala area in Sweden, as follows: 68.4 sec for inner city, 43.2 sec for suburbia and 57.4 sec for rural areas. Although the bin size is not defined, these values are in good agreement with the observed figures in the MoN. The authors also report an average collection speed of 20, 30 and 60 km/h for inner city, suburbs and rural areas, respectively. This is higher than the values achieved in MoN (conditions comparable with the inner city in Uppsala). Possible explanation is twofold: 1) different conditions of the road network and traffic in the two cities; and 2) a denser matrix of collection points, due to a higher population density, allowing for shorter distances travelled between collection points and therefore lower speed. Nevertheless, the vehicle speed used for central roads in Nikea (15 km/h) compares well with the inner city collection speed in Uppsala (20 km/h).

The optimal solution expressed in S2 (Fig. 5) corresponds to 9.8 km of distance travelled by the waste collection vehicle. This is a 12.5% improvement when compared to the existing empirical route (S0).

The improvement is more emphatic in terms of the total travel time in the optimal route, defined as the runtime of the collection vehicle plus collection time for the waste bins (component 2 + component 3). The total travel time in Sector 1 for the optimal route is 259 minutes (a 17% reduction compared to the empirical route S0).

Route distance and time savings become all more important when considered on a weekly basis. In the current scheme, Sector 1 is divided into two sub-sectors.

Table 2: Comparative results of the different waste collection scenarios.

Scenario	Route distance (km)	Route time (min)	Improvement from empirical route % Distance (time)
S0: Empirical scheme	11.2[1]	312[1]	-
S1: Routing on S0	10.6[1]	304[1]	5.5 (3.0)
S2: Bin reallocation and Routing	9.8[2]	259[2]	12.5 (17.0)

[1]two sub-sectors, 4+4 trips per week
[2]one combined sector, 7 trips per week

Fig. 5: Optimal waste collection vehicle route.

Waste is collected four times per week for each sub-sector, resulting to a total of eight collection trips per week. Therefore, weekly route distance and time for S0 amount to 89.6 km and 2,496 min, respectively.

To this, the hauling time to Fyli landfill (30 km from Sector 1) should be added. Assuming an average speed of 60 km/h, allowed by the fact that waste collection in Greece is mainly performed at night, in order to avoid traffic congestion and reduce nuisance to the residents, the travel time to and from Fyli amounts to about one hour. However, as Fyli landfill is the only disposal site for the whole Attica region, serving a population of approximately 4.5 million people, significant delays of as much as two hours, are common for the waste trucks before they can empty their load. According to data from MoN and the aforementioned assumptions, a typical average hauling time of 2.5 hours (150 min) can be considered, or 1200 min on a weekly basis. Adding the collection and hauling distance and time travelled, S0 requires on a weekly basis a travel of 480 + 89.6 km and 1200 + 2496 min.

Corresponding figures for S1 are 480 + 84.8 km and 1200 + 2432 min, while for S2, 420 + 68.6 km and 1050 + 1813 min. As S2 performs the same collection work in 7 trips only, covering the entire sector each, weekly savings are higher than indicated in Table 2 for individual trips.

Restricting the discussion to the collection phase only of the entire WC&T cycle, it is expected that fuel consumption relates more to time of operation and number of stops than distance travelled, as most of the collection time is spent for bin loading and emptying [1, 30]. Fuel consumption and corresponding CO_2 emissions are functions of work performed for stopping and accelerating, actual driving, traffic related stops and lifting and compacting the waste [1]. Therefore, even for the same distance travelled, changes in the number of stops, i.e. the number of the collected bins, will affect fuel consumption in a manner similar, if not proportional, to the change of collection time.

This heavy dependence of collection time on the number of stops constitutes the main explanatory factor for the differences in the percentage savings in distance and time in S1 and S2. The ratio of % savings of distance to % savings of time is neither unity nor the same for the two optimisation scenarios. In S1 distance savings are larger than time savings, as the optimisation referred to routing only, on the same number of bins as the current empirical situation. Routing using the GIS model developed resulted to a 5.5% improvement of the distance travelled; as however the number of stops remained the same, time (and fuel) savings were smaller. In S2, the main optimisation intervention consisted of the introduction of a smaller number of larger bins and, to a second level, their reallocation. As a result a larger time saving (17%) was achieved compared to the distance one (12.5).

6 Conclusions

In this study GIS technology was used for the development of a methodology for the optimisation of commingled MSW collection. The method uses various geographical data (road network, location of waste bins, land uses etc) in co-operation with advanced spatial analysis GIS tools. The model was applied in the case study of one waste collection sector of the MoN, Athens, Greece, to examine routing optimisation of the existing scheme (S1) and scheme improvement through bins reallocation (S2).

Results indicate that the optimal scenario (S2) is more efficient in terms of collection time and distance travelled. These savings are highly related to gas emissions and fuel consumption savings.

The study demonstrated the value of GIS technology as a waste collection optimisation tool, capable of guiding decision making. Future work should focus on sectorisation of wider waste collection areas, based on spatial analysis rather than empirical approaches, as well as adaptation of the collection system to the introduction of separate collection schemes for different waste streams and quantification of fuel and emission savings.

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