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A GIS BASED TECHNIQUE FOR DETERMINATION OF OPTIMAL NUMBER AND SPATIAL LOCATION OF WASTE BINS – CASE STUDY OF KRAGUJEVAC

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Abstract

This paper concerns the development of a methodology aimed at determination of optimal number of waste bins as well as optimizing their spatial location. The methodology used was based on a Geographic Information system which handled different sets of information, such as street directions, spatial location of objects and number of inhabitants, location of waste bins and radius of coverage. The study was conducted on a district in a center of the City of Kragujevac. The results indicated reduction of 24% in number of collection points and 33.4% in number of waste bins, without reducing the quality of provided services. It has led to costs and time savings for waste collection and also to environmental benefits.

Keywords: waste collection, collection point locations, energy efficiency

Introduction

Urbanization, as one of the most evident global changes worldwide, leads to dramatic increase in urban solid waste generation with a great socio-economic and environmental impact. Therefore, solid waste management is one of the most complex tasks that city authorities are faced with. Municipal solid waste management is a multidisciplinary activity that includes generation, storage and collection, transport, treatment and waste disposal. Waste collection and transport account for 50% to 70% in total costs of the system. The share is higher at landfill-based management where waste is directly entering landfill without any treatment. This is very common in developing countries, as well as in Serbian cities.

Municipal companies are trying to make the best possible way to provide their services. Since such a service is very expensive many towns and cities are forced to reassess their solid waste collection plan and to optimize the system in order to make energy efficient and economic sustainable system. In recent years many optimization model have been proposed. Researchers seem to agree that an ideal collection system should be adapted to local conditions, and take into account cultural, demographic, geographic, economic and social factors. There can be found numerous researches on fuel consumption, time required and pollutants emission during waste collection and transport. Sonesson [1] presented a general approach to calculate fuel consumption and time taken for waste collection. According to this author, driven distance and number of stops are two parameters that have the greatest influence on fuel used and pollutants emission. Other parameters were not taken into account. Nguyen [2] showed a great influence of vehicle idling time on total

fuel consumed, as well as variable fuel rates for different collection stages. Zsigraiova [3] combined vehicle route optimization and waste collection scheduling with historical data of filling rate of each container to estimate operation costs and pollutants emission reduction. In addition, influence of dynamic loading process was considered. In the recent past, a geographic information system became an essential tool for waste collection optimization and reduction of fuel consumption. Many researchers used this tool to improve waste collection and transport [4-6]. Proper spatial location of waste bins and their number according to demographics could make system for solid waste management more efficient. Keeping in mind fact that GIS deals with spatial data, it is very common to solve this kind of problem by using GIS software. Using ArcGIS for processing of spatial database, Karadimas [7] made a research in Athens. The main issues of the research were spatial location and number of waste bins. As a result of calculation for analyzed city's district, the number of containers was reduced for 30% which presents great energy and environmental savings. Another research, where spatial location for waste bins was in focus, was made in Spain in the City of Chuarriana de la Vera [8]. This research proposed an algorithm that facilitates the allocation of different types of waste containers with a view to optimizing the waste collection service. As starting point, the radius of influence of each container was less than 75 meters. Authors showed that it was possible to reduce the number of containers without reducing their service efficiency.

Route optimization for waste collection and transport in the City of Kragujevac, using the possibilities of GIS, were made in previous researches [9-11]. As a result of these studies the reduction of 14% in total length travelled was achieved, which indicated great saving in total fuel spent. The lower environmental impact of optimizes routes was also analyzed [12]. The study presented in this paper describes a developed methodology for evaluation of current waste collection points as well as evaluation of number of waste bins according to demography and commercial activities in buildings.

Study area

The city of Kragujevac is situated in the center of Republic of Serbia and it is the fourth largest city in the country. According to official results of the 2011 census, the city has a population of 150.835 inhabitants, while administrative area has a population of 179.417. The city of Kragujevac generates about 55.000 tons of solid waste each year.

Municipal company Čistoća is responsible for solid waste management in the city of Kragujevac. Waste management is based on the landfilling. All of the collected waste beside primary separation (paper, glass, PET) is directly transferred to landfill in Jovanovac, which is 3 kilometers away from the city center. The city is empirically divided into 11 sectors (collecting zones). Twenty communal vehicles are engaged for waste collection and transport. Waste generated in households and commercial objects is temporary stored in waste bins. The company has about 3000 large waste bins (1100 litres) located at 1450 collection points, while in some areas, usually at city suburb, exist certain number of small waste bins (120 litres).

Area that will be under examination into this paper is shown in Figure 1. This part of the city belongs to sector one with waste collection at daily level. This is a very representative area because it consists of huge number of residential building, offices, shops, restaurants as well as faculty and student dormitory. The area under study has 263 waste bins of 1.1 m^3 located at 116 collection points. As mentioned

before, waste collection is at daily level and vehicle usually makes two collection trips to empty all the waste bins in the area. According to measurements, the weight of collected waste varies between 11 and 12 tones.

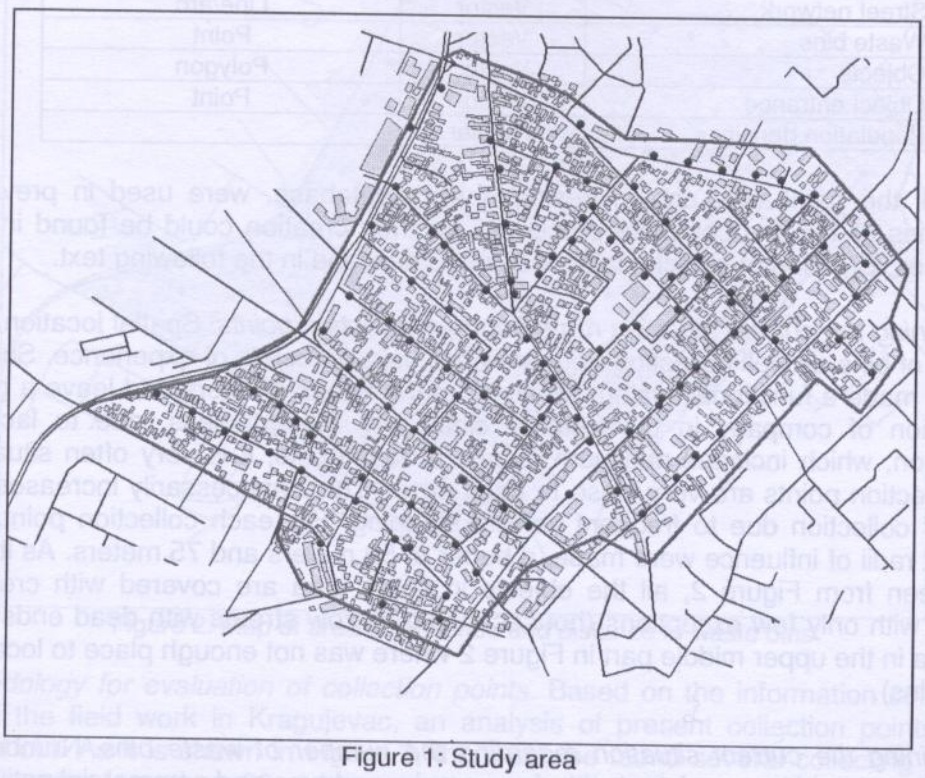

Figure 1: Study area

Materials and methods

This paper proposes a model whereby a GIS is used to determinate an optimal model for improving energy efficiency in the area under study which includes number and positions of waste bins, and also finding the shortest route to collect waste from new locations. For this purpose ESRI ArcGIS 10.1 software application was used. It is integrated system for creation, management, integration and analysis of geographic data. This software includes various integrated applications and extensions. One of them, that was used in this research, is ArcGIS Network Analyst, which is very powerful extension that provides network based spatial analysis including routing, travel directions, closest facility and service area analysis. Before the analysis could be perform, all necessary data must be collected. This includes:

- Ortofoto city map
- Street network map
- Waste bins database
- Objects database

The types of spatial geodata and their geometric representation are shown in Table 1.

Table 1: Types of spatial geodata and their geometric representation

Geodata	Type	Geometric representation
City map	Raster	-
Street network	Vector	Line/arc
Waste bins	Vector	Point
Objects	Vector	Polygon
Object entrance	Vector	Point
Population density	Tabular	-

Since all the databases above, beside objects database, were used in previous researches [9-11], the complete procedure for their creation could be found in the references. Creation of objects database will be describe in the following text.

Determining the current situation regarding the collection points. Spatial location and number of bins as well collection frequency are usually results of experience. Such a practice made a functional system which meet the needs of users and leave a good impression of company in the form of clean city. Nevertheless, due to lack of calculation, which includes minimum energy requirements, it is very often situation that collection points are very close to each other. This unnecessarily increases the costs of collection due to frequent vehicle stopping. For each collection point two different radii of influence were made, a buffer of 50 meters and 75 meters. As it can been seen from Figure 2, all the objects in study area are covered with created buffers, with only few exceptions (houses in two narrow streets with dead ends and one area in the upper middle part in Figure 2 where was not enough place to locate a waste bins).

Determining the current situation regarding the number of waste bins. Number of waste bins should be consistent with demography and type and commercial activities in the area of collection point influence. Similar to collection points, number of waste bins is usually result of experience. It often occurs that the average weight per container is far below the weight corresponding to the full container, in accordance with the waste composition. This make total price of waste collecting even higher, because of non-proper number of waste bins or collection frequency.

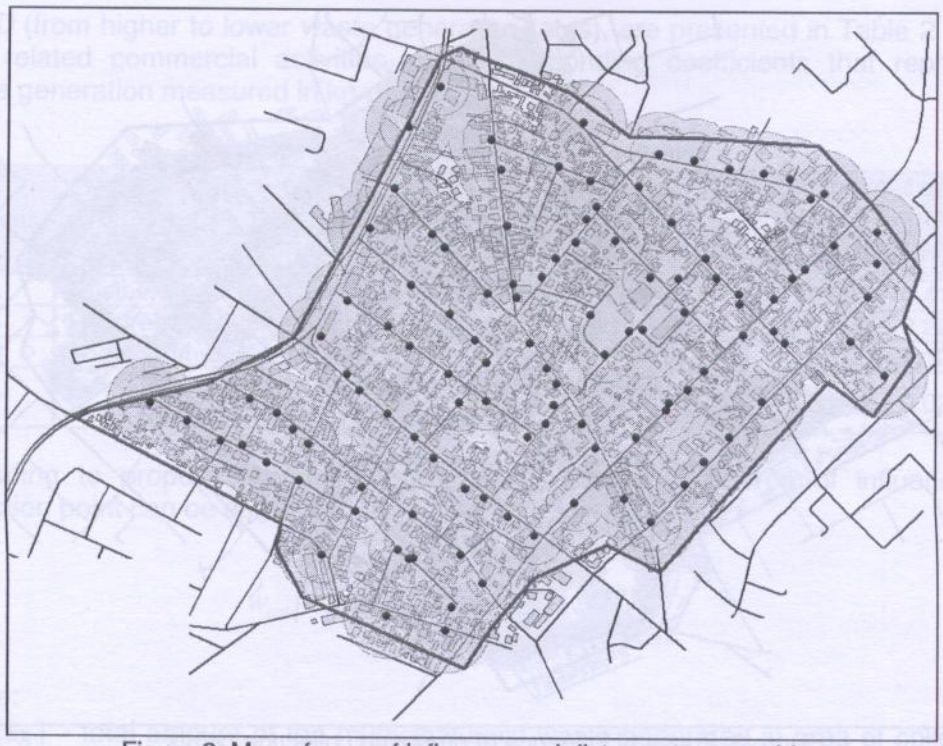

Figure 2: Map of area of influence and distance to waste bins

Methodology for evaluation of collection points. Based on the information collected during the field work in Kragujevac, an analysis of present collection points was carried out. As it is shown in Figure 2, there can be found several collecting points with distance less then 20 meters among each other. According to the available literature, it is considered that the distance of 75 meters does not diminish the comfort of citizens in waste disposal [8]. Consequently, in area under study certain number of ineffective collection points could be removed and some of them could be allocated. New locations of collection points should be homogenous distributed along the streets and in coordination with current locations. New distribution should also include field work, to get sure if new location for collection point is proper and the waste bins don't interfere with traffic. Allocation of collection points were made by trial and error method.

After collection points were allocated to proper locations, distances of citizens to waste bins should be calculated again. Ring buffers around collection points do not represent real walking distance from buildings to waste bin. More appropriate method is to use option Service area available in extension Network Analyst. This option uses street network to determinate which objects are in given impedance from collection points. Also, new layer had to be created. This layer consists of entrance in buildings or in the yards (depends if entrance in building is directly from street or building has a yard). Another field work should be made, using GPS device all entrances were identified and spatial geodatabase in GIS environment was created. Figure 3 shows improved positions of collection points, as well as polygons with 75 meters walking distance.

Figure 3: Zones of influence of proposed collection points

Methodology for evaluation of waste bins number. After optimal spatial locations of collection points were defined, the next step is to define optimal number of waste bins for each collection point. Only the essential number of waste bins should be used, as exaggeration increases the collection cost, especially in cases like the area under study, where the waste is collected at daily base. In order to achieve this, the total amount of waste generated, in zone of influence of each collection point, must be calculated. Formed polygons which represent the zone of influence of collection points, do not overlap each other. Thus, for each location it can be determined the total number of covered buildings (Figure 4).

Figure 4: Polygon coverage

In afore mentioned buildings database, for each building a specific data were recorded. Every commercial and/or residential activity was identified. The relative data included street name and number as well as number of residences. Furthermore, commercial activities were categorized and the surface covered by each one was calculated. According to waste generation, all commercial activities were divided into four classes. The selected classes, which are denoted as *A, B, C*

and *D* (from higher to lower waste generation rates), are presented in Table 2 along with related commercial activities and corresponding coefficients that represent waste generation measured in kg per m^2.

Table 2: Classes of commercial activities

Classes	Typical commercial activity	Commercial activity coefficient $c_{wi}[kg/m^2]$
A	Restaurant, bakery, fast food, fish store, bar, pub, etc.	0.398 – 0.419
B	Hairdresser, butcher store, floristry, garage, pizzeria, etc.	0.200 – 0.225
C	Theatre, church, bookstore, pharmacy, post office, etc.	0.109 – 0.124
D	Insurance company, betting shop, shoe store, jewelry store, etc.	0.011 – 0.024

According to proposed model, total waste generated into area of influence of collection point can be calculated using equation (1):

$$w_{tot} = n \cdot w_{cap} + \sum_{i=1}^{4} c_{wi} \cdot A_i \qquad (1)$$

where:

$w_{tot}[kg]$ - total amount of the municipal solid waste generated in area of collection point influence;

n - number of citizens living in covered area;

$w_{cap}[kg]$ - daily waste generation rate per capita;

$c_{wi}[kg/m^2]$ - commercial activity coefficient and

$A_i[m^2]$ - total surface area of commercial activity class.

The adopted daily waste generation rate per capita, for area under study, is 1 kg. It is a bit higher value than average daily generated rate in the City of Kragujevac, since area under study belongs to city's center with the greatest waste generation rate.

Essential number of waste bins could be calculated using equation (2):

$$N = \frac{w_{tot}}{w_{wb}} \qquad (2)$$

In eq. 2, *N* presents a number of waste bins for selected collection point and w_{wb} presents amount of waste in full waste bin. According to waste composition in area under study, adopted value for w_{wb} is 100kg (for 1.1m^3 waste bin filled up to 90% of volume). Since the obtained result for number of waste bins – *N* is usually in decimal format, for final result first higher integer is taken.

Results and discussion

The results achieved using developed methodology are shown in Figure 5.

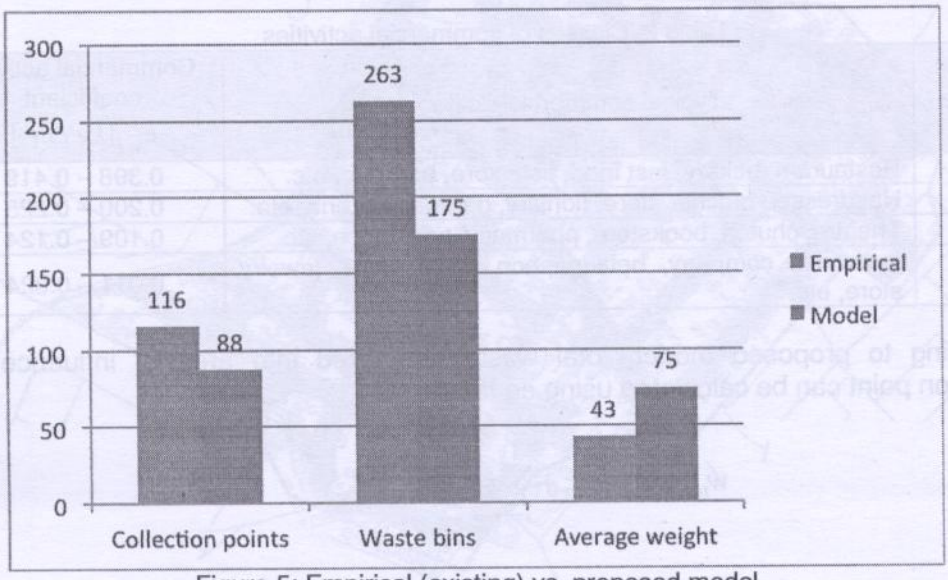

Figure 5: Empirical (existing) vs. proposed model

When talking about number of collection points, it has been possible to bring about significant reduction – from 116 to 88 without reducing their service efficiency. This will contribute to a less number of vehicle stops in the process of waste collection and thus reducing the fuel consumption.

In the proposed model, the number of waste bins, according to demography and commercial activities in area under study, is 33.4% less compared to current situation. This reduction effects on fuel consumption and time taken for bin lifting and empting. Since average time for empting one waste bin is 50 seconds, collection of all waste in area under study would last more than one hour less compared to present situation. Also, average weight of waste per waste bin increased from 43 to 75 kg.

Figure 6 shows optimized vehicle route for waste collection in case of proposed locations of collection points. Compared to optimized route for current situation, which has been done before, there is no significant result is route shortness.

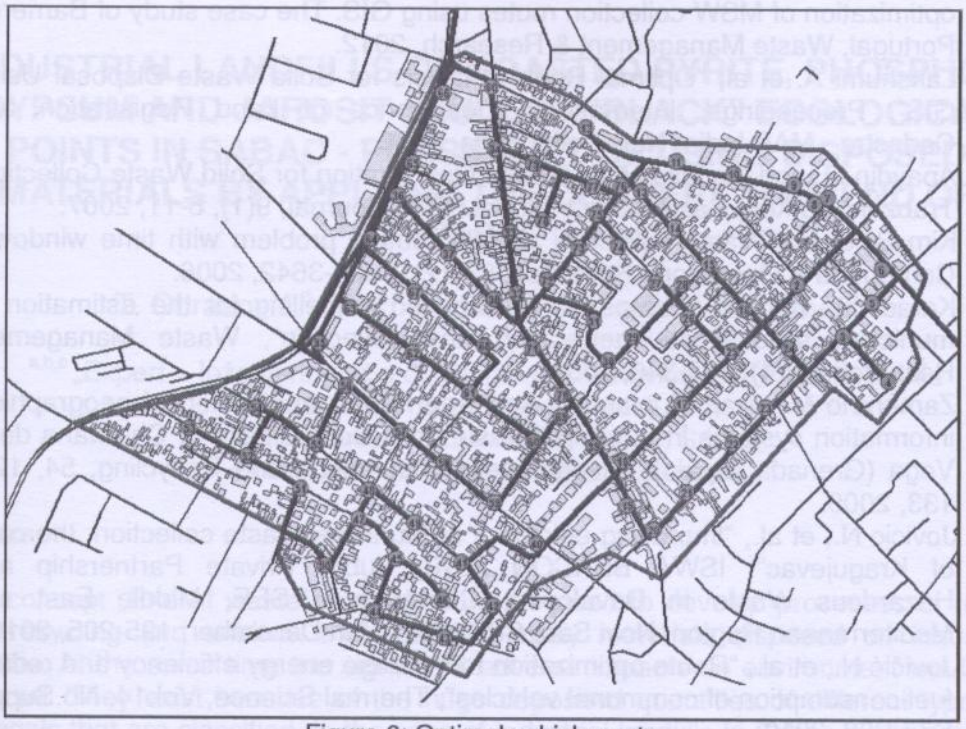

Figure 6: Optimal vehicle route

Conclusions

This paper focuses on the design and implementation of methodology for evaluation of location of waste collection points as well as number of waste bins in accordance to demography and commercial activities in area under study. The developed methodology is based on using a GIS environment. For presented research ESRI ArcGIS software package with Network Analyst extension was used.

By adopting the proposed model, significant savings could be achieved. In the actual case study the number of collection points could be reduced by more than 33% and number of waste bins by 24%. This improvement guarantees more energy and environmental efficient waste collection with less fuel consumption and time taken.

Furthermore, as a part of this research, several tools were developed. These tools are related to data collection and geodata bases creation. Due to luck of waste management information systems, these tools could be used in any municipality in Serbia for their creation. The existence of information systems is essential prerequisite for the improvement of the system for solid waste management.

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