ISWA BEACON 2010

Public Private Partnership and Hazardous Waste

in Developing Countries in SEE,
Middle East and Mediterranean Region
8th-10th December 2010,
Serbia - Novi Sad

PROCEEDINGS

ISWA International Solid Waste Association - ISWA
SeSWA Serbian Solid Waste Association - SeSWA

Faculty of Technical Sciences
Department for Environmental Engineering
Autonomous Province of Vojvodina
Provincial Secretariat for Architecture and Urban Planning

ISWA Beacon 2010
Public-private partnership and hazardous waste in developing countries in SEE, Middle East and Mediterranean Region

PROCEEDINGS

EDITORS
Doc. Dr. Goran Vujić
Prof. Dr. Anđelka Mihajlov
Prof. Dr. Aleksandar Jovović
Antonis Mavropoulos

Novi Sad, December 2010.

Address:
Dr. Goran Vujić
Faculty of Technical Sciences
Trg Dositeja Obradovica 6
21000 Novi Sad, Serbia
Tel: + 381 21 485 2458
Fax: + 381 21 475 0048
E-mail: contact@iswabeacon.rs

Acknowledgment:
Ministry of Science and Technological Development
of Republic of Serbia has supported printing
of the Conference Proceedings

SESSION 4

SWEEP-Net: The regional solid waste exchange of Information and expertise network in MENA region; A new platform for regional cooperation in the field of solid waste Management
W. Gallala

Waste incineration in Slovenia: a life-cycle assessment of environmental impacts of potential waste-to-energy options
S. Malek

Improving Efficiency of Municipal Waste Collection: The Case of Kragujevac
N. Jovicic et al

Environmental Assessment of Ramici Landfill (Banja Luka) by Means of LCA-Modeling (Easewaste)
D. Bjelic et al

Waste to energy from specific waste streams: the case study of Cyprus
A. Karkazi et al

Optimization of transport cost of collection waste cooking oil in Banat region
A. Djuric et al

Analysis Of Motor Vehicle Recycling In Serbia By The Application Of Lca
B. Milanovic et al

***An Example Of The Valorisacion Of Plastic Waste From The Region Of Southern Banat* Banat**
M.N. Topalovic et al

IMPROVING EFFICIENCY OF MUNICIPAL WASTE COLLECTION: THE CASE OF KRAGUJEVAC

N. Jovicic [*a], G. Boskovic [a] , M. Milasinovic [a], G. Vujic [b] and G. Jovicic [a]

[a] Faculty of Mechanical Engineering, Sestre Janjic 6 Kragujevac, Serbia,
e-mail: njovicic@kg.ac.rs
[b] Faculty of Technical Science, Department of Environmental Engineering, Trg Dositeja Obradovića 6, Novi Sad, Serbia, goranvujic@uns.ac.rs

**Corresponding Author:* njovicic@kg.ac.rs

Abstract

Collection and transportation within the system of solid waste management may account more than 60% of the overall budget, most of which is for fuel costs. Furthermore, municipal vehicles have great environmental impact through exhaust gases emissions. The aim of this research was to estimate the potential for reduction of fuel consumption and thus the emission of CO_2 through the communal vehicles route optimization. Innovative model for municipal solid waste collection and transportation is proposed. This model is part of an extended solid waste management system and uses a spatial Geodatabase, integrated in a GIS environment. All the paths of communal vehicles within one sector (collecting zone) of City of Kragujevac were analyzed and optimized, by using commercial software, according to criteria of shortest distance. Optimized routes indicate to great fuel savings compared to the origin one. In addition, street classification was made and each street segment was attributed with average fuel consumption. In order to evaluate fuel consumption factor the method proposed in COPERT software was used. Thus, the most economical route was extracted and also compared to the origin one and the optimized route concerning shortest distance.

Keywords: Energy Efficiency, Solid waste management, Route optimization, Street Classification, Fuel consumption.

Introduction

Urbanization is one of the most evident global changes worldwide. The rapid and constant growth of urban population has led to a dramatic increase in urban solid waste production. Furthermore, the result of the increased solid waste generation is environmental degradation and it is one of the greatest problems. Effective solid waste management planning is one of the major issues faced by municipal authorities. The main goal in solid waste management is optimization of the system with minimization of costs and increasing of energy efficiency, with the respect to all constancies adjusted by the users of the system.
The system for solid waste management consists of waste generation, storage and collecting of waste, waste transportation, waste treatment and waste disposal.
High level of complexity and variability are the main characteristics of the system for solid waste management. A lot of significant factors have influence on the system, and those factors are variable, especially talking about quantity and quality (morphology) of generated waste, number of citizens, characteristics of traffic, legal framework, etc.

The basic functional principle of system for solid waste management is to satisfy a global goals which are established by solid waste management strategy (at the state and local level) to seek for development and optimization of main elements. Techno-economical

analyze of the system shows that the collection and transport of solid waste may account more than 60% of all expenses, therefore some improvements in those sub-systems are necessary in order to establish more efficient and economical sustainable municipal system for solid waste management.
Considering the improvement of system for solid waste management by improving collection and transport elements, 3 levels of improvement can be made: 1) strategic level – selection of lasting solid waste management technology 2) tactical level – selection of economical sustainable places for transfer stations 3) operational level – defining more efficient system for waste collecting at local (city's) level [1].
Tactical and strategic levels of improvements of the system for solid waste management are limited to legal, economic and political framework and, as such, they are beyond the opportunities of typical municipal service.
Hence, the improvement of communal services, in order to create preconditions for defining energy efficient and economically sustainable system for solid waste at the local level, imposes itself as the only mode in which can guarantee the achievement of projected goals in precisely defined time frame.

Solid waste management in the world

In the last few years improvement and optimization of the municipal system for solid waste management is issue of interest and research in the whole world, especially in some segments of the system. Special emphasis is placed on routing optimization and optimization of waste bin locations.
The routing optimization problem belongs to model known as Vehicle Routing Problem (VRP). Application of VRP model leads to feature of many new models which include most of constrains from the real life waste collection [2]. Geographical Information System (GIS) also plays a vital role in finding the "cheapest"/shortest routes for communal vehicles [3, 4]. Particularly, in the simulation process and making the variant solutions for communal vehicle routes GIS provides much necessary information, such as geo-referenced maps, name of the roads and their width, location of storage bins, demographics data, etc. Constrains from the real life waste collection should be taken into account in VRP optimization models. Most important constrains are capacity and number of communal vehicles, work shift duration, variability of traffic conditions, variation of waste production over year, limited time of waste storage in bins, etc. All of the mentioned things lead to very complex models which are very hard for implementation. Furthermore, usage of the strictly models is reduced to simple models, and in the other side complex models had to be solved by including heuristic methods such as tabu-search or genetic algorithms. Thus, the final conclusion is that there is no universal solution for optimization of system for solid waste management and each problem is unique and has to be taken into consideration as unique.
As far as the published results of the research are concerned, a several typical examples can be identified. Lakshumi [4] presented the results of study for the city of Chennai in India which has a population of 4.5 million. The aim was to determinate the optimal route for solid waste collection and to compare the cost of new optimized and present routes. The commercial software package ArcGis was used and at the example of one treated route the savings in length of 41,5% in day shift and 44% in night shift was made. Apaydin [5] published results of the research in route optimization for solid waste collection for the city of Trabzon in Turkey. The city of Trabzon is as large as the city of Kragujevac and has 185.000 inhabitants. For 39 districts in the city, a shortest path model was used in order to optimize solid waste collection/hauling processes, as minimum cost was aimed.
The Route View ProTM software as an optimization tool was used for that purpose and the success was around 4-59% for distance and 14-65% for time. The total benefit was 24% in total costs or about 18.014 $ monthly.

Karamidas [6] showed the results of research in optimization the number and the positions of the waste bins in the Municipality of Athens. Spatial database were made in GIS and were taken into account for calculating in ArcGis software package. According to calculations in the area under study the number of waste bins has been decreased from 162 to 112 which is the 30% and presents the great saving in used energy for the waste collection. Tavares [9] made a research in the city of Praia, where 3D street model was made and effects of road inclination and vehicle weight were taken into account. Using ArcGis software the calculations were made and the most fuel economical route was found. The savings were 8% in fuel consumption even the most economical route was 1,8% longer then the shortest route.
In our neighborhood some research can be identified in Croatia, published by Carić [7]. The municipal vehicles paths were analyzed in the city of Zagreb and some improvements were made with the developed numerical method. The results indicated possibility of decreasing the number of vehicles from 7 to 6 and saving of 30% in the traveled path.

Solid waste management in Serbia and the City of Kragujevac

Up to date significant research effort in Serbia in area of optimization of solid waste management is not indicated. The fact is that public companies in Serbia do not have recorded infrastructure of system for solid waste management at the level of GIS application. The region city division, spatial distribution of sites for waste collecting and discharge rate of waste bins are often the result of experience, and not the principle of minimum energy expenditure. Considering the municipal vehicle paths the situation gets more complicated and without making prerequisites through implementation of system's resource database (by GIS requirements) every optimization attempt is already made to be a failure. Therefore, development and implementation of basic system's database model could have a possibility to be used in every company with similar activities.
The aim of this research was to estimate the potential for reduction of fuel consumption and thus the emission of CO_2 through the communal vehicles route optimization. In order to meet the defined aim there are several modalities of the aim:

- Development and implementation of basic model of municipal system for solid waste management database (Environmental information system of Kragujevac) at the level of GIS application
- Implementation of system for monitoring of waste collection over the Internet
- Implementation of methodology for defining energy costs of the process of collecting and transport of waste in the existing system of routes
- Development and implementation of methodology for the optimization of the waste collection and transport system based on GIS technology (route optimization)

Spatial database

In order to analyze the current situation and identify the optimum scenario for waste collection and transport, in terms of minimizing the financial and environmental costs, the first step is to create the spatial database with all necessary elements – city's environmental information system. This system is directed on collecting, storing and processing significant information which are about volume-energy properties of the municipal wastes and the dynamic of the system as well. The aim of the system is to raise the level of energy efficiency and environmental protection of the city and the region of Central Serbia.

The developed system store in the database all the necessary information, such as population density; number, type and the positions of waste bins; road network and the related traffic; number, type of trucks, capacities and their characteristics; the current routing system of the collecting vehicles; the geographic boarders and the characteristics of waste collection sectors. The main effort in the creating the mentioned database was to create a database of the waste bins locations and the database of the current vehicle's paths. In the following text this will be detail described.

For recording of current situation, locations of waste bins and the collecting vehicle's tracks the GPS devises Garmin Colorado 300 and Trimble Juno were used. The recorded data was transferred to Garmin software MapSource with the city map. The locations of waste bins in the MapSource are shown in the Figure 1.

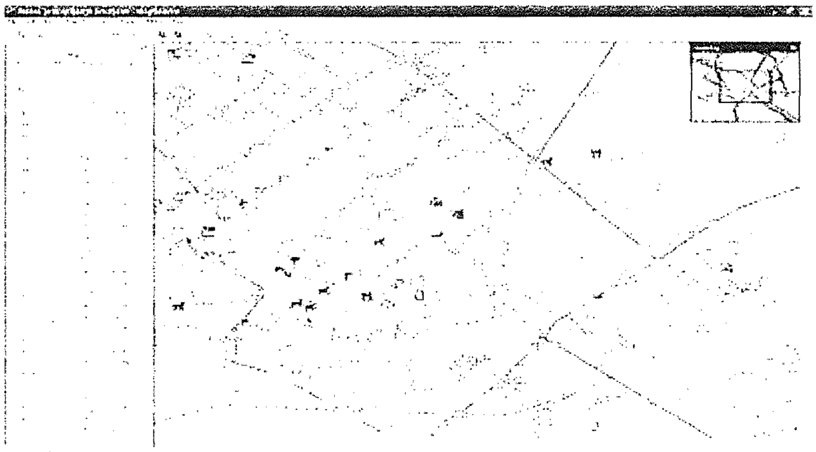

Figure 1: MapSource database

The database also has records of all the collecting vehicle's tracks witch can be shown in the city map too. Beside the GPS coordinates the database was updated by non-spatial data such as unique ID, bin number, bin type/capacity, photography and bin collection time for each location of waste bins, and unique path ID, vehicle average speed, travel time and number of emptied waste bins for each vehicle's path.

The database was modified and the user can access database through the Google Earth software. This software was chosen because it is free, it is very user friendly and the user can have all the information about waste bin location or the vehicle path by one mouse click. The Figure 6 presents the Google Earth with waste bin locations. By clicking on the waste bin location the table which includes all the data from the database will appear.

Figure 2: Google Earth database

The vehicles paths can also be presented and analyzed trough this software.
For the optimization of the collecting process a spatial database was modified and implemented into standard commercial GIS environment (ESRI, ArcGis). This choice ensures compatibility with the availably data from the Municipality of Kragujevac (street network, city raster map) and access to analysis available from the software.

System for monitoring of waste collection over the Internet

The complete history of municipal vehicle paths is necessary for the full control of waste collection and disposal process. For this purpose, system for satellite vehicle tracking "G-target AVL" developed by Serbian company Eforte was used. At the moment this system is implemented in one truck but the plan is to implement in all vehicles. G-target AVL is integrated system for monitoring and control of the vehicles which use system for global positioning (GPS), GSM network (GPRS) and Internet. The system consists of **G-Target** devise which is installed in vehicle, server's software **G-Target SRV** which receives and sand data from G-Target devise to client's software **G-Target CLI** installed on user's computer. The system allows user to remotely collect information about vehicle movement at the city map.
G-Target device determinate the vehicle's position using GPS module built in the device (latitude, longitude, velocity, driving direction, time, etc.), compress the attained data and send them over the GSM network and Internet to server's software G-Target SVR. G-Target SRV receives the data from the devise and put them into database. In the same way it receives the commands from the user and sends them to the devise over the client's software G-Target CLI.

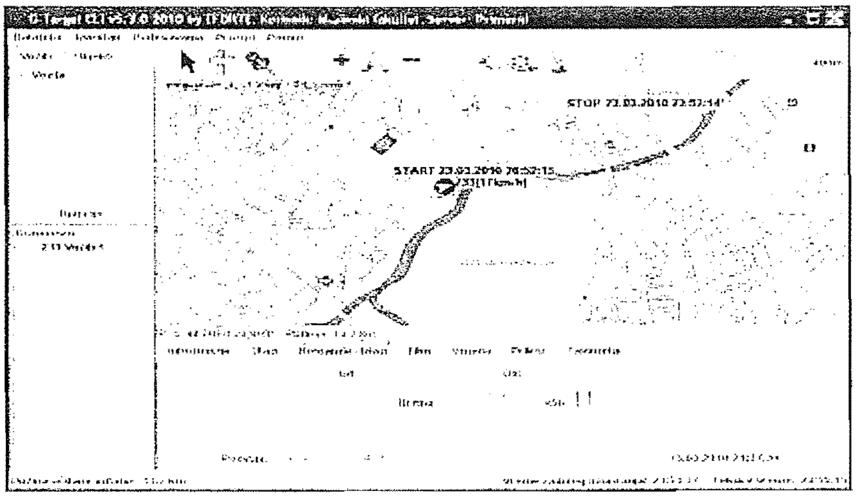

Figure 3: G-Target CLI software

The system has a possibility of the real time GPS/GPRS vehicle tracking and displaying the data at city map. The user can supervise the vehicles and thus reduces the costs and prevents misuses (in the municipal vehicles case this forces drivers to drive the paths defined by the management and not the one they choose). There is Internet archives of the history of movement. The vehicles don't have to be supervised all the time, there is the possibility to see the history with simulation. Figure 3 shows the G-Target client software with the city map with the current position of vehicle and its path.

Methodology for defining energy costs

In order to define energy costs in the current system of collecting vehicle's routes, it is necessary to measure the collected waste in vehicle and to record data in the database. City's landfill is equipped with electrically scale and each vehicle is measured before dumping the waste. Vehicle has its unique ID and it is connected with database of vehicle paths. In that way it is easy to identify energy costs of collecting and transport of waste and to define number of kilometers that vehicle run to collect one ton of waste, liters of fuel per ton of collected waste or number of minutes spent per one waste bin. The shown data at Figures below is at yearly level.

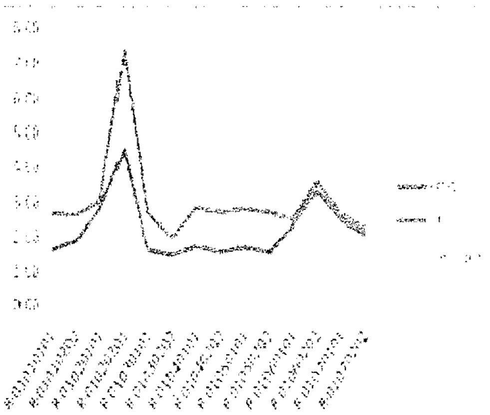

Figure 4: Energy costs in sector 1

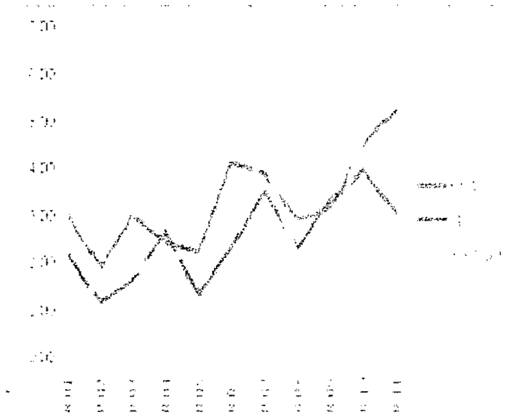

Figure 5: Energy costs in all sector

Figure 4 shows energy costs in one of city's sectors and figure 5 shows distribution of costs in all sectors.

Methodology for the optimization of the waste collection (route optimization)

The methodology used in this research has tree general steps. Step 1 develops the spatial database of study area described above. Step 2 performs the optimization of routing for minimal time and distance with the use of ArcGis Network Analyst GIS software. In addition, step 3 expands the street network database with fuel consumption factor for each street segment and performs the optimization of routing for minimal fuel consumption.
The content of spatial database in GIS environment is summarized in the Table 1.

Table 1.

Spatial data	***Type***	***Geometry***
Road network	Vector	Line
Waste bins	Vector	Point
Existing run routes	Vector	Polygon
Road network attributes/restrictions	Tabular	-
Waste bins' attributes	Tabular	-
City map	Raster	-

Special attributes of street network also were registered. These attributes include traffic rules, topological conditions, special restriction (turn restrictions, U turn restrictions). These attributes provide real-world road network conditions.

Figure 6: Study area

The city of Kragujevac is empirically divided into 11 sectors (collecting zones). Study area in this research is sector 4 and it is presented in Figure 6.
The total area under study (sector 4) is 4 km^2 and includes 305 loading spots with total 700 waste bins. The are 7 different vehicle routes. All of the routes were analized and optimized using ArcGis software.
The problem of vehicle routing is: each vehicle must travel in the study area and visit all the waste bins (that vehicle visit in the origin route) and to minimize the distance or time.
Table 2 presents the savings in 7 optimized routes after the ArcGis calculations were made.

Table 2

Route	Origin route [km]	Optimized route [km]	Savings [km]	Savings [%]
R0401	17,3	16,7	0,6	3,59
R0402	19,6	15,4	4,2	27,27
R0403	24,3	20,6	3,7	17,96
R0404	29,4	28	1,4	5,00
R0405	30,3	27,6	2,7	9,78
R0406	25,8	20,6	5,2	25,24
R0407	32,2	29,4	2,8	9,52

Figure 7 and Figure 8 present one of the routes (R0402) in sector 4, the origin and the optimized route respectively.

Figure 7: The origin route

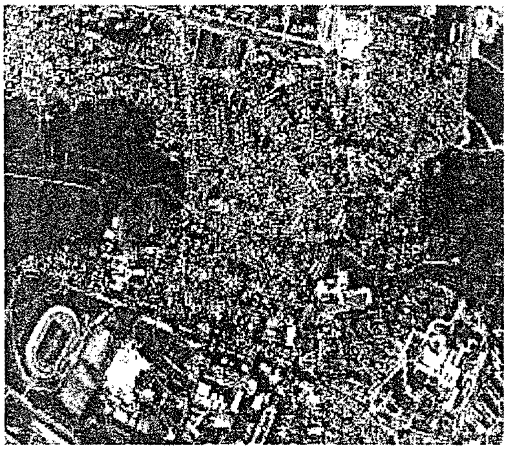

Figure 8: The optimized route

The total saving after optimizing all the different routes in the research area is 20,6 kilometers, and multiplied with number of days in one week (when vehicles run the same routes) and with number of weeks in one year, the total saving is over 6.000 kilometers at year level.

Route optimization for minimal fuel consumption

After the route optimization from criterion concerning the distance was made, it was necessary to expand the existing database and to prepare data necessary for fuel-economical route optimization. The structure of the developed model with components for optimization is shown on figure 9 [10].
Each street segment, as a part of a street between two junctions, was attributed with Fuel Consumption Factor (fc). The most fuel-economical route has the lowest Total Fuel Consumption (TFC) expressed by equation (1):

$$TFC = \sum (Lseg_i fc_i) \tag{1}$$

where $Lseg_i$ presents the length of street segment with matched fc_i.

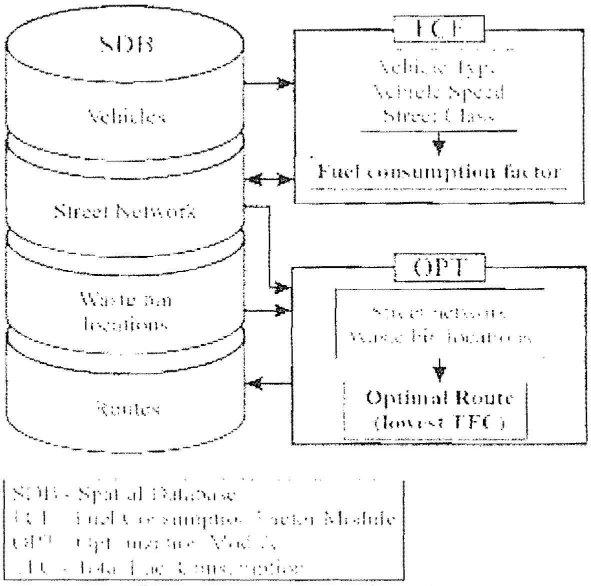

Figure 9: Developed model

Calculation of fuel consumption (fc)

Fuel consumption during waste collection depends on type of the vehicle, travelled distance and actual operating conditions of a given vehicle. In order to calculate the total fuel consumption, method proposed in the computer program COPERT was used [11]. COPERT is a program that calculates road vehicle emissions and has a framework for estimating fuel consumption for specific vehicles. In this study data available in COPERT for the category of diesel heavy duty vehicles and EURO I legislation class was used. The basic fuel consumption as a function only of speed (V), $FCS\,(g/km)$, is expressed by equation (2):

$$FCS = 1068{,}4V^{-0.4905} \tag{2}$$

In this equation a speed value was taken from the local environmental information system of Kragujevac, mentioned above. Characteristic data concerning vehicle speed and GPS position were taken from GPS devise and stored in database. Using the GPS data, the position of the vehicle could be compared with the location in the digital map for each segment of the street with a unique key number. Furthermore, the fuel consumption vary on different street types and traffic conditions, so the Street Class Factor (SCF) has to be included in fuel consumption (fc) equation (3):

$$fc = FCS * SCF \tag{3}$$

Street Class Factor is defined for each segment of the street in database.

Classification of street types

In the present study the classification of street types was made according to four criteria: *type of environment, street wideness, density of junctions controlled by traffic lights* and *traffic-calming measures* [12]. These four criteria are shown to be of specific importance for emissions and fuel consumption factors. Combinations of these street types give numerous street classes but some of those classes are very rare so some street types were merged. The final number of street classes is 17.

Type of environment: The type of environment have a great influence on traffic jam and fuel consumption. According to this criterion there are free types of streets: 1) streets in rural area, 2) streets in urban area and 3) streets in extra urban area.

Street wideness: According to street wideness there are two types of streets: 1) streets with one lane in the same way and 2) streets with two lanes in the same way.

Density of junctions controlled by traffic light: The density of junctions controlled with traffic light affects fuel consumptions and emissions. Also the STOP signs and a give way signs decrease the average vehicle speed. According to this criterion there are four street types: 1) street segment controlled with traffic light, 2) streets with stop or give way signs and 4) streets with no traffic light or stop or give way sign.

Traffic-calming measures: This criterion divides the streets in two types: 1) streets with traffic-calming measures (such as speed humps, curb extensions, etc) and 2) without traffic-calming measures.

After the street classification was done 17 possible street classes were made. Each street segment was joined in one of the 17 street classes and attributed with proper Street Class Factor (SCF). SFC is not a result of experiment and measuring the real fuel consumption. It is estimation of fuel consumption for different street classes and different traffic conditions according to the available similar published data [12].

After assigning fuel consumption factor to each street segment the optimization in ArcGis software was performed. Figure 10 shows the most fuel economical route calculated by ArcGis software.

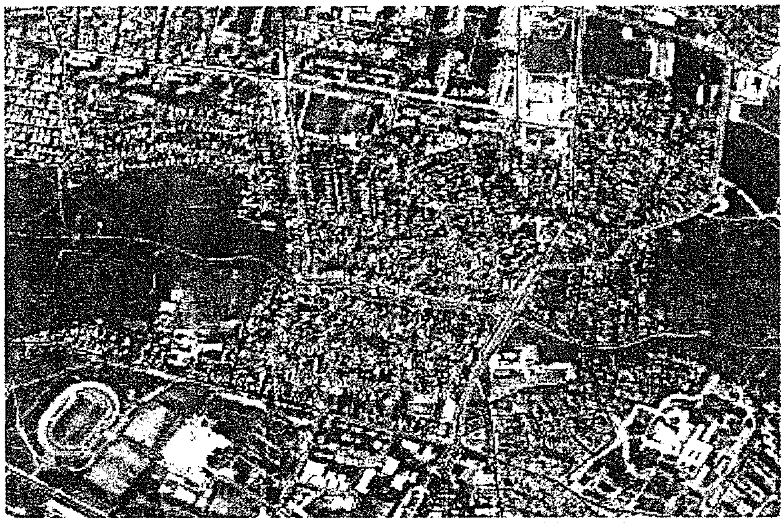

Figure 10 The optimal route calculated by software

The most fuel-economical route was extracted and compared with the route extracted from criterion concerning shortest distance. Total travelled for this route was 15.9 km, and that is 0.5 km longer than the shortest distance. The ratio between TFC in optimized routes concerning lowest fuel consumption and shortest distance is:

$$TFC_2 / TFC_1 = 0.94 \tag{4}$$

where TFC_1 is the total fuel consumption for shortest distance route and TFC_2 is total fuel consumption for lowest fuel consumption route. The result indicates 6% of savings in fuel consumption for the second route, and shows that the shortest route is not necessarily the most economical.

Conclusions

The City of Kragujevac produces about 57.000 tons of solid waste per year. According to the accessible information during 2009, 20 municipal vehicles were engaged. For the collection and transport of solid waste over 20.000.000 RSD for fuel and oil were spent. Total maintenance costs were 6.800.000 RSD.

According to above research, and published world experiences in this field the total savings vary from 20 to 40% in collection and transport of solid waste. Keeping in mind this fact it is fair to expect 20% of savings in total costs. This means 6 million RSD in total costs.

Emission of CO_2 for typical municipal vehicle (with Euro 1 engine) is 900 g/km and when is multiplied with number of kilometers and number of vehicles it goes to 213.000 kg of CO_2 emissions in the atmosphere per year. Route optimization leads to great savings in total costs and also it would be a great benefit in environmental protection, 40 tons of CO_2 less each year. To keep in mind the fact Kragujevac produces about 1000 tons of solid waste per week, Novi Sad and Nis 1700-2000 tons and Belgrade over 10.000 tons per week it can be concluded that significance of this research is much wider.

Development and implementation of basic model of municipal system for solid waste management database would have the great influence on functionality of typical municipal service. Methodology establishing for improvement of energy efficiency in solid waste management gives an opportunity to each municipal company to make better and more efficient system.

Concerning most fuel-economical route, in order to get more realistic results, it is necessary to make more field experimental research and to determinate Street Class Factor for each class of street. This would be the aim of future research.

References

1. Erdelez A. et al, „Integrate Approach in Solid Waste Management" (in Croatian), Građevinar, 59(6): 505-516, 2007.
2. Kim B. et al, "Waste collection vehicle routing problem with time windows" Computers & Operations Research, 33(12): 3624-3642, 2006.
3. Karadimas N. and Loumos V., "GIS-based modelling for the estimation of municipal solid waste generation and collection", Waste Management Research, 26(4): 337-346, 2008
4. Lakshumi A. et al, "Optimal Route Analysis for Solid Waste Disposal Using GIS", Proceedings, International Conference of Land Registration and Cadastre - MAP India, New Delhi, India, 2006.
5. Apaydin O. and Gonullu M.T., "Route Optimization for Solid Waste Collection: Trabzon (Turkey) Case Study", Global NEST Journal, 9(1): 6-11, 2007
6. Karadimas N. et al, "Routing Optimization Heuristic Algorithms for Urban Solid Waste Transportation Management", WSEAS Transaction on Computers, 7(12): 2022-2031, 2008.
7. Tavares G. et al, „Optimisation of MSW collection routes for minimum fuel consumption using 3D GIS modelling", Waste Management, 29(3): 1176–1185, 2009.
8. Carić T., „Improving of transport organization using heuristics methods", (in Croatian), Ph.D thesis, University of Zagreb, Croatia, 2006.
9. Jovičić N. et al, „Locale Environmental Information System", Proceedings, 2. National conference of life quality, Kragujevac, Serbia, 2007.
10. Jovičić N. et al, "Route Optimization to Increase Energy Efficiency and Reduce Fuel Consumption of Communal Vehicles", Thermal Science, 14(4), 2010
11. Ntziachristos L. and Samaras Z., „COPERT III – Computer Programme to Calculate Emissions from Road Transport, Methodology and Emission Factors" (Ver. 2.1), European Environmetal Agency, Copenhagen, Denmark, 2000.
12. Ericsson E. Et al, „Optimizing route choice for lowest fuel consumption – Potential effects of a new driver support tool", Transportation Research Part C, 14(6): 369–383, 2006

ISBN 978-86-7892-305-0

www.iswabeacon.rs