ROUTE OPTIMIZATION TO INCREASE ENERGY EFFICIENCY AND REDUCE FUEL CONSUMPTION OF COMMUNAL VEHICLES

by

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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. General methodology for route optimization is also presented. For the area under study, detailed field experimental research in the City of Kragujevac was conducted. Using GIS and GPS technology, whole municipally infrastructure for waste collection was scanned and all paths of communal tracks was recorded and allocated in developed database. Based on experimental and numerical results, one typical municipal vehicle route was analyzed by using ArcGis software. The obtained result indicates 2700 km of possible savings per year concerning one communal vehicle. In addition, the most fuel-economical route was extracted and compared with the original route, and with the routes extracted from criterions concerning the traffic time and shortest distance. According to available information for the City of Kragujevac and the results from this study, it was estimated that the total savings could be 20% in costs and the associated emissions.

Keywords: *solid waste management, route optimization, street classification, fuel consumption.*

Introduction

At this level of development of human society, without making any difference between rich and poor, urban and rural areas, environmental degradation is one of the greatest problems and it is the result of increased solid waste generation. In order to find a solution for

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a concrete municipal problem at a level of one local community there are different functional elements (sub-systems) and each of them is part of one system known as municipal system for solid waste management. Furthermore, 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.

System for solid waste management

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 make almost the half 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].

The first case appears in the process of planning long-term functioning of the system for solid waste management. Also in the analysis, revises or in adoption of new strategies for further development (the reason of obsolescence, the appearance of a new legal framework, or the appearance of new sustainable technologies). In this case it is necessary to consider all elements of waste management in order to determine the long-term development policies. The selection of treatment technologies significantly affects on the organization of transportation of waste, and time and costs, which indirectly has a broader impact on the environment. Different technologies lead to different transport subject, different destinations and distances. The more different fractions of waste that should be separately managed cause the more complex transportation system and more expensive vehicles. Therefore, choosing sustainable treatment technologies for optimization of system for solid waste management is a systematic approach to resolve this complex engineering problem. In the decision-making process it is necessary to include more optimization criteria that must be simultaneously taken into account.

Lower (tactical) level of optimization of system for solid waste management means the choice of economic sustainable locations for transfer stations appears when regional system for solid waste management is already established and/or when the area becomes too big. The introduction of transfer station in the system is of major importance for the rationalization and reduction of costs. Tactical decisions ensure the implementation of strategic decisions and criteria for their evaluation are performance of the system in whole.

Operational level of system improvement means defining more energy efficient system at local level and it is permanent task for each municipal company and this task should be carried out every several years. This level involves the solution for following problems: 1) adequate positioning of waste bins consistent with population density and the level of urbanity (improved or optimized frequency of waste bins discharges) 2) city area division consistent with vehicle fleet (better use of vehicle's capacity) 3) municipal vehicle route optimization (decrease in fuel and spare parts costs). This kind of optimization is necessary because the basic factors that affect environmental often vary. Some of the factors are: number of inhabitants, quantity of solid waste, types of vehicles used and their capacity, traffic volume details, *etc.*

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.

Research in optimization of solid waste management

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 [7] made a research in the city of Praia, where 3-D 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 [8]. 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.

Situation 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 city of Kragujevac or the municipal company Čistoća, has about 4000 waste bins placed at 2000 locations within 12 city divisions. Currently there is electronic record of spatial distribution of waste bins and municipal vehicle paths in the final phase. Hence, development of software tools and methodology, organization procedures and technology for database resource processing could be example of good practice for all other local communities in Serbia.

Implementation of system for monitoring of waste collection

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 (figure 1) 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 1. G-Target devise

The functional possibilities of the system are:

- The 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);
- 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;
- Points of interests can be placed at the city map (waste bin position), and then it is possible to see in report if the vehicle passed nearby some points in the radius which is defined by the user of the system;
- Detection of activated sensors means that the devise can detect if the engine is turned on, if the door is open, *etc.* For the municipal vehicle would be very interesting to build in the

sensor for waste bin lifting, and in that case if the sensor is activated then the bin was emptied for sure;
- Transferred data over the Internet is compressed so the price of exploitation is low, and
- If the GSM network is unavailable the devise records the data to own memory and transfers when the network becomes available again thus the history is always accessible. The built-in memory is big enough to record the path over 30 days.

Environmental information system of Kragujevac

Locale environmental information system of Kragujevac uses the existing frame of that system which came as the result of earlier research at the Faculty of Mechanical Engineering in Kragujevac [9]. 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.

For recording of current situation, locations of waste bin and the vehicle’s tracks the GPS devise Garmin Colorado 300 was used. The data recorded by this equipment was transferred to city map and store in electronic form for further analyses. The waste bin locations database, beside the GPS coordinates, includes number and type of bins, photography and the day and time of empting the bin. This information should be published on the Internet and in that way each citizen would be able to access the database and to find out the time of empting the bin on requested location.

Route optimization

In this research, one typical day shift of one communal truck was analyzed. The area under study is about 5 km^2 and includes 88 loading spots with total 200 waste bins.

For generating the optimal route the following data are needed:
- City raster photo map,
- Street network with non-space attributes (name of street, driving directions, speed limits),
- Number of waste bins and their locations,
- Capacities of the bins,
- Time taken for collection of solid waste per bin,
- Type of vehicles used and its capacity, and
- Existing run routes for the communal vehicles.

This data was taken from the database mentioned above.

Figure 2 shows the present route which length is 30.9 kilometers. Also, the figure shows 2 characteristically segregate locations of waste bins at park near car factory. Before running any calculation in ArcGis software route analyze shows that it would be economical sustainable to except those locations from the route and in that case the route length would be 27.9 kilometers. The excepted locations could be added to vehicle which runs nearby the car factory and if 2 mentioned locations were added the route would increase for 500 meters. Furthermore, by combination of those 2 routes the saving would be 2.5 km which is the 8% of the analyzed route. Keeping in mind the fact that the truck runs this route 6 times per week the conclusion is that modification of route brings the savings of 780 km yearly.

After all the data was prepared the ArcGis calculations could be made. Figure 3 shows the optimum shortest distance route calculated by ArcGis. The route length is 22.2 kilometers. The experimental results confirm an improvement of the optimum route by about 21.8% in comparison with the present route (without 2 segregate locations). This improvement reduces the collection and transportation costs of the trucks considerably, as might be expected.

Table 1. Route optimization

	Length	Savings in %	Savings in km	Savings per year
Current route	30.9 km			
Analyzed route	28.4 km	8.1%	2.5 km	780 km
ArcGis optimized route	22.2 km	21.8%	6.2 km	1930 km
Total		28.1%	8.7 km	2710 km

Table 1 summarizes the computational test results which indicate to 28.1% in route length. The total savings for this optimized route is 2710 kilometers per year.

Figure 2. The current route

Figure 3. The optimized route

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 4.

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):

$$TFC = \sum(Lseg_i \, fc_i), \qquad (1)$$

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

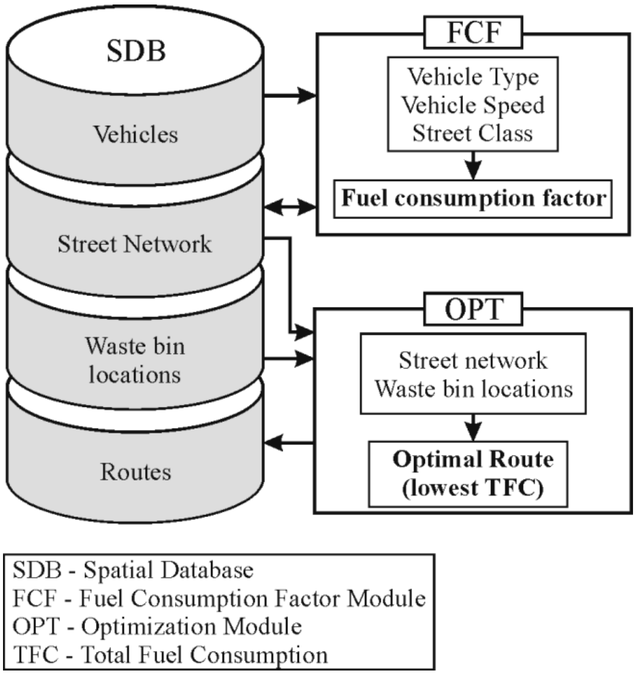

Figure 4. The structure of the developed model

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 [10]. 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^{-1}], is expressed by equation (2):

$$FCS = 1068{,}4\, V^{-0{,}4905} \tag{2}$$

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):

$$fc = FCS \text{ x } SCF \tag{3}$$

SCF 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* [11]. 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.

Table 2 shows 17 classes and their descriptions. 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 [11].

Table 2. Street classes and their descriptions

Street class	Area	N^o of lanes	Traffic light	Stop or give way sign	Traffic-calming measures	Street class factor (*SCF*)
1	rural	2	no	no	no	1.00
2	rural	1	no	no	no	1.05
3	rural	1	no	yes	no	1.10
4	urban	2	no	no	no	1.15
5	urban	2	yes	no	no	1.20
6	urban	1	no	no	no	1.25
7	urban	1	yes	no	no	1.30
8	urban	1	no	yes	no	1.35
9	urban	1	no	no	yes	1.40
10	urban	1	no	yes	yes	1.45
11	extra urban	2	no	no	no	1.50
12	extra urban	2	yes	no	no	1.55
13	extra urban	1	no	no	no	1.60
14	extra urban	1	no	yes	no	1.65
15	extra urban	1	no	no	yes	1.70
16	extra urban	1	no	yes	yes	1.75
17	extra urban	1	yes	no	no	1.80

Figure 5. The most fuel economical route

After assigning fuel consumption factor to each street segment the optimization in ArcGis software was performed. The most fuel-economical route was extracted and compared with the route extracted from criterion concerning shortest distance. Total travelled for this route was 22.6 km, and that is 0.4 km longer than the shortest distance. The ratio between *TFC* in optimized routes concerning lowest fuel consumption and shortest distance is:

$$TFC_2 \text{ x } (TFC_1)^{-1} = 0.95 \tag{4}$$

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 5% of savings in fuel consumption for the second route, and shows that the shortest route is not necessarily the most economical. Figure 5 shows the most fuel economical route calculated by ArcGis software.

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 237.354 liters of fuel and 8770 liters of oil were spent. Total maintenance costs were 5.800.000 RSD. By the available facts system for solid waste management in Kragujevac spends about 30 million RSD each year.

According to above study 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 50.000 liters of fuel, 1.500 liters of oil and 1.200.000 RSD in spare parts less per year or 6 million RSD (65.000 €) in total costs.

Conclusions

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 213.618 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.

As it was already emphasized there is no record of significant research in field of improvement and optimization in solid waste management in Serbia. Consequently, 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 solve following problems:

- Adequate positioning of waste bins consistent with population density and the level of urbanity (improved or optimized frequency of waste bins discharges),
- City division consistent with vehicle fleet (better use of vehicle's capacity), and
- Municipal vehicle route optimization (decreases in fuel and spare parts costs).

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., Margeta, J., Knezić, S., Integrate Approach in Solid Waste Management, (in Croatian), *Građevinar, 59* (2007), 6, pp. 505-516
[2] Kim, B., Kim, S., Sahoo, S., Waste Collection Vehicle Routing Problem with Time Windows, *Computers & Operations Research*, *33* (2006), 12, pp. 3624-3642
[3] Karadimas, N., Loumos, V., GIS-Based Modeling for the Estimation of Municipal Solid Waste Generation and Collection, *Waste Management Research*, *26* (2008), 4, pp. 337-346
[4] Lakshumi, A., Ramiya, A., Ssthya, R., Optimal Route Analysis for Solid Waste Disposal Using GIS, *Proceedings on CD,* International Conference of Land Registration and Cadastre – MAP India, New Delhi, India, 2006
[5] Apaydin, O., Gonullu, M.T., Route Optimization for Solid Waste Collection: Trabzon (Turkey) Case Study, *Global NEST Journal*, *9* (2007), 1, pp. 6-11
[6] Karadimas, N., *et al.*, Routing Optimization Heuristic Algorithms for Urban Solid Waste Transportation Management, *WSEAS Transaction on Computers*, *7* (2008), 12, pp. 2022-2031
[7] Tavares G., *et al.*, Optimization of MSW Collection Routes for Minimum Fuel Consumption Using 3-D GIS Modeling, *Waste Management*, *29* (2009), 3, pp. 1176-1185
[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 on CD*, 2nd National Conference of Life Quality, Kragujevac, Serbia, 2007
[10] Ntziachristos, L., Samaras, Z., COPERT III – Computer Program to Calculate Emissions from Road Transport, Methodology and Emission Factors (Ver. 2.1), European Environmental Agency, Copenhagen, Denmark, 2000
[11] Ericsson E., Larsson H., Brundell–Freij K., Optimizing Route Choice for Lowest Fuel Consumption – Potential Effects of a New Driver Support Tool, *Transportation Research Part C, 14* (2006), 6, pp. 369-383

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