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METHODOLOGY FOR REDUCTION OF GHG EMISSIONS FROM MUNICIPAL SOLID WASTE COLLECTION AND TRANSPORT

Abstract: *Collection and transport of municipal solid waste (MSW), as a part of solid waste management, have a great environmental impact due to exhaust emissions from fuel combustion. Distance traveled appears as one of the most influencing parameter in total fuel consumed. This paper presents a general methodology for route optimization using Geographic Information System (GIS). The necessary databases were created and established methodology was applied to waste collection and transport system in the city of Kragujevac. Using GIS software one typical route was optimized. Furthermore, fuel consumption and associated exhaust emissions vary in different waste collection and transport stages. Waste collection and transport circuit was divided into four different stages. The estimation of Greenhouse Gas (GHG) emissions for optimized route was made and compared to estimated emissions of current route. Calculations, which also include vehicle speed as very important parameter, indicated great savings in GHG emissions.*

Keywords: *MSW, collection and transport, GHG emissions, GIS, route optimization*

1. Introduction

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. This proportion is higher at landfill-based management where waste is directly landfilling without any treatment. This is very common in developing countries. Collection and transport of waste is ussualymade by heavy-duty trucks that have a great environmental impact due to diesel fuel consumption and pollutants emission. There can be found numerous researches on fuel consumption and pollutants emission during waste collection and transport. Sonesson (Sonneson, 2000) presented a general approach to calculate fuel consumption and time 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 and Wilson (2010) showed a great influence of vehicle idling time on total fuel consumed, as well as variable fuel rates for different collection stages. Zsigraiova *et al.* (2012) combined

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vehicle route optimization and waste collection scheduling with historical data of filling rate of each container to estimate operation costs and pollutants emmision reduction. In addition, influence of dynamic loading process was considered. Tavares *et al.* (2009) made a research in the city of Praia, where 3D street model was made considering effects of road inclination and vehicle weight were taken into account. The savings were 8% in fuel consumption even the most economical route was 1.8% longer then the shortest route.

By optimization of process of waste collection and transport, both economic and environmental savings could be achived. Development of Geographic Information System as well as specialized software enabled progress in this field. Lakshumi*et al.* (2006)presented the results of study for the city of Chennai in India that has a population of 4.5 million. The aim was to determinate the optimal route for solid waste collection. Commercial software package ArcGIS was used and savings of 40% was achieved. Karamidas*et al.* (2008) showed the results of research in optimization of container's number in the Municipality of Athens. According to the calculations made in ArcGIS software, number of containers has been decreased from 162 to 112 representing great saving in energy used for waste collection. Apaydinand Gonullu (2007) published results of research in route optimization for solid waste collection in the city of Trabzon in Turkey. For 39 districts in the city, the shortest path model was used in order to optimize solid waste collection/hauling processes, as minimum cost was aimed. The Route View ProTM software has been used as an optimization tool. Final benefit was 24% in total costs. In our neighborhood some research could be identified in Croatia (Caric, 2006). The municipal vehicles routes were analyzed in the city of Zagreb and some improvements were made with the developed numerical method. Results indicated possibility of decreasing the number of vehicles from 7 to 6 and saving of 30% in distance traveled.

This paper presents estimation of pollutants emission for different stages of waste collection and transport process as well as methodology for route optimization using GIS. Vehicle average speed has been taken into account as a parameter that has great influence on amount of pollutants emitted.

2. Waste collection and transport

The basic activities in the MSW collection and transport process could be divided into four different activity stages, as shows in Figure 1.

At the beginning of working day vehicle starts from the municipal company garage. Empty truck is travelling to the collection area. This is the first stage in MSW collection and transport process.

Second stage starts by entering the collection area. The truck stops at first collection point and continue idling while the crew takes the container to the truck. Container is lifted, using hydraulic mechanism, and collected waste is unloaded to the truck. The crew returns the container to previous place and this process is repeating until all the containers at collecting point were empty. After that, truck accelerates and travels to the next collection point where, as described above, unloading containers. Second stage lasts until the truck is full loaded.

Third stage starts by leaving the collection area and driving to the unloading point (landfill, transfer station or waste treatment plant). At this point collected waste is measuring and unloading, and by this activity one circuit of waste collection and transport is finished.Another circuit starts departing from landfill (transfer station or waste treatment plant) and driving to another collection area that represents stage I, described above. Each circuit starts the same way and ends by unloading of collected waste. At the end of working day the truck drives back to garage that represents the fourth stage of the process of MSW collection and transport. The path that truck drives for one working day presents the truck route which, by definition, consists of several circuits.

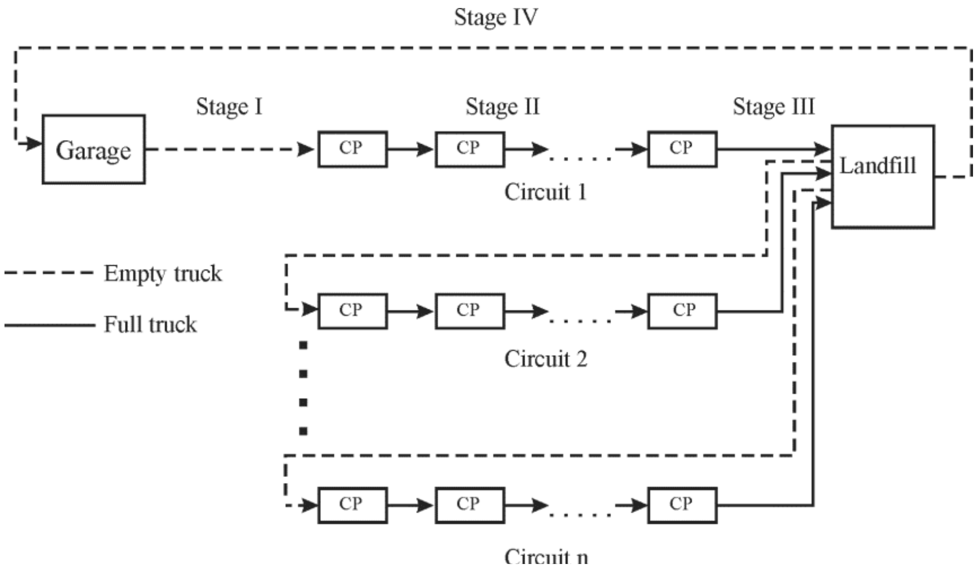


Figure 1. Stages of waste collection and transport process

Stages I, III and IV present the MSW transport. During these stages vehicle drives through the city's streets network. In the stage III truck is full and in the stages I and IV the truck is empty. Transport comprises distances driven by empty or full truck and, in terms of energy, can be described in liters of fuel per tonne per kilometer. Under these conditions, fuel consumption and emission of GHG can be estimated using vehicle manufacturer data, such as average consumption of vehicle according to truck's loading level, for urban driving. In addition, GHG emissions could be estimated by using LCA software.

Stage II presents waste collection that can be defined as the driving from first to the last collection point of one collection circuit (or trip). It should be noticed that fuel consumption and emissions under these driving conditions are very different compared to waste transport. Driving conditions during the waste collection vary depending on city region, but also vary within a single region (different container unloading time, different distances between collection points, etc.). Due to the above issues, detail analysis of each collection route and inclusion of more parameters in the calculation is necessary to obtain more precise solution.

3. Fuel consumption and GHG emissions

During the process of waste collection and transport, the main parameter that influences the level of fuel consumption is the distancetraveled. Apart of that, there are other important parameters, such as vehicle speed, acceleration, road inclination, number of stops, vehicle load, etc.Furthermore, actual operation conditions are variable during the stages of waste collection and transport.

In the course of transport of waste fuel is spent for travelling outside the collection area and for idling caused by stops in urban traffic conditions. The amount of spent fuel and associated GHG emissions are linear with the distance traveled.

During the waste collection truck consumes fuel for travelling within the associated collection area and idling while unloading the containers. Idling time, very often, reaches the 50% of the total route time spent. According to available literature, idling fuel consumption rates are ranking from 2.3 to 4.0 liters per hour for heavy duty trucks (Larsen *et al.*, 2009). Also, keeping in mind that waste collection means stop at every collection point, fuel consumption is even higher due to very often vehicle's acceleration/deceleration and changing engine's operation conditions.

As mentioned above, in the process of waste collection and transport, route optimization for the shortest distance traveled and reducing number of stops have the greatest influence to total operation costs reduction and GHG emissions.

Total amount of emitted pollutants depends on total distance traveled and actual engine operation conditions. According to (Zsiagriova*et al.*,2012)poluttants emission could be calculated by following equations:

$$E_i = \sum_{vehicle\ route} \left(E_{i,hot} + E_{i,cold}\right) \tag{1}$$

$$E_{i,hot} = \varepsilon_{i,c} d_{tr} \tag{2}$$

$$\varepsilon_{i,c} = \left(k_1 + av + bv^2 + cv^3 + \frac{d}{v} + \frac{e}{v^2} + \frac{f}{v^3}\right) * \left[\left(k_2 + rv + sv^2 + tv^3 + \frac{u}{v} - 1\right) z + 1\right] \tag{3}$$

$$E_{i,cold} = \varepsilon_{i,cold} N \tag{4}$$

Where E_i, $E_{i,hot}$ i$E_{i,cold}$ are the total emissions of pollutant *i* (g), the hot emissions of pollutant *i* (g), and the cold emissions of pollutant *i* (g), respectively. $\varepsilon_{i,c}$ presents the hot emission factor for pollutant *i* corrected for load (g/km), $d_{tr}$is distance traveled (km); *v* is the average velocity (km/h), k_1, *a*, *b*, *c*, *d*, *e*, *f*, ik_2, *r*, *s*, *t*, *u* are coefficients depending on the vehicle total weight and *z* is the fraction of transported load; $\varepsilon_{i,cold}$is cold emission factor for pollutant*i* (g/cold start), and *N* is number of cold starts. The values of the coefficients appearing in Eq.(3) are shown in Table 1 for heavy-duty vehicle with gross weight in the range 7.5-16 tonnes.

Table 1. Values of coefficients appearing in Eq. (3) (Zsiagriova*et al.*,2012)

Pollutant	Parameter
CO	k_1= 3.08; a = - 0.0135; b = 0; c = 0; d = - 37.7; e = 1560; f = - 5736; k_2 = 1.03; r = 9.77e^{-4}; s = 0; t = 0, u = 0
CO_2	k_1= 871; a = - 16; b = 0.143; c = 0; d = 0; e = 32031; f = 0; k_2 = 1.26; r = 0; s = 0; t = - 2.03 e^{-7}; u = - 1.14
NO_x	k_1= 2.59; a = 0; b = - 6.65 e^{-4} ; c = 8.56 e^{-6} ; d = 140; e = 0; f = 0; k_2 = 1.19; r = 0; s = 0; t = 0; u = - 0.977
PM	k_1= 0.0541; a = 1.51 e^{-3}; b = 0 ; c = 0; d = 17.1; e = 0; f = 0; k_2 = 1.02; r = 2.34 e^{-3}; s = 0; t = 0; u = 0

Table 2 shows the values of the coefficients appearing in Eq. (4).

Table 2. Values of coefficients appearing in Eq. (4) (Zsiagriova*et al.*,2012)

Pollutant	Vehicle type (tonns)	Parameter $\varepsilon_{i,cold}$ (g/cold start)
CO	7.5-16 16-32	6 6
CO_2	7.5-16 16-32	300 500
NO_x	7.5-16 16-32	-2 -5
PM	7.5-16 16-32	0.6 0.6

It should be noticed that even acceleration/deceleration of vehicle have a great influence on fuel consumption and pollutants emission, these parameters are not cosidered. On the other hand, vehicle average velocity in different waste collection and transport stages are taken into account. Consequently, results obtained using this methodology, are certainly more accurate compared to results obtained by LCA software, that simplifies the calculation and do not take into consideration variable operation conditions.

4. Route optimization – the case of Kragujevac

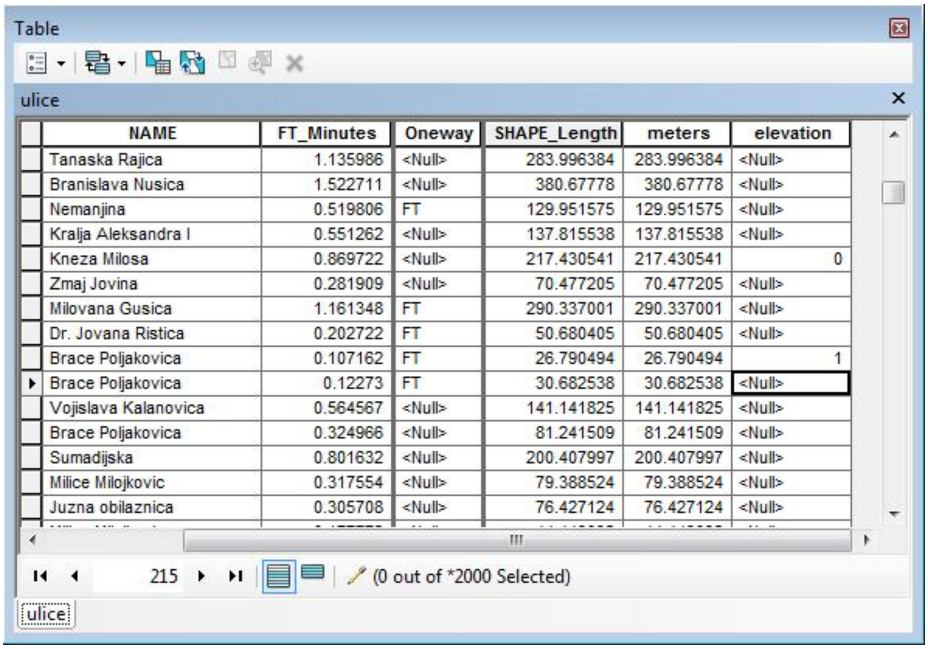
In order to evaluate the potential effectiveness of different waste collection routes, the Network Analyst (NA) extension of ESRI's ArcGIS ArcMap 10.0, was used. NA uses Dijkstra algorithm to determinate the shortest path source-destination of the network, and Tabu-Search as the VRP solving method. According to previous researches (Jovicic*et al.*, 2010a; Jovicic*et al.*, 2010b), for optimization of the existing vehicle's routes, the following data are necessary:

- City ortophoto map
- Street network map
- Collection points database
- Current municipal vehicles routes

City ortophoto map was provided by municipality of Kragujevac. The type of map is raster and it is consisted of 24 parts in tiff format. In order to use this map as a background layer it had to be georeferented, in other words the map had to be positioned on the right coordinates.

The street network map, used in this research, was also provided by municipality of Kragujevac. The map was in CAD format, so it had to be adjusted to GIS environment. The polyline shapefile was edited from city map, in CAD format, and after that network file was created. Network is a system of interconnected elements which must be well connected in order to work properly and to create route. Each street is represented with polyline and it is attributed with series of variables from attribute table. These attributes were added to simulate real traffic conditions in process of waste collection and transport.

Figure 2 shows attribute table that consists of parameters which are acquired directly from the network during creation, such as Shape_Length that represents the length of streets in meters. Parameters that represent traffic restrictions were added also. This is concerned on Oneway, U-Turn restrictions, Elevation, etc. Time attribute assigned to streets was captured with GPS device for each street.



Table

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NAME	FT_Minutes	Oneway	SHAPE_Length	meters	elevation
Tanaska Rajica	1.135986	<Null>	283.996384	283.996384	<Null>
Branislava Nusica	1.522711	<Null>	380.67778	380.67778	<Null>
Nemanjina	0.519806	FT	129.951575	129.951575	<Null>
Kralja Aleksandra I	0.551262	<Null>	137.815538	137.815538	<Null>
Kneza Milosa	0.869722	<Null>	217.430541	217.430541	0
Zmaj Jovina	0.281909	<Null>	70.477205	70.477205	<Null>
Milovana Gusica	1.161348	FT	290.337001	290.337001	<Null>
Dr. Jovana Ristica	0.202722	FT	50.680405	50.680405	<Null>
Brace Poljakovica	0.107162	FT	26.790494	26.790494	1
Brace Poljakovica	0.12273	FT	30.682538	30.682538	<Null>
Vojislava Kalanovica	0.564567	<Null>	141.141825	141.141825	<Null>
Brace Poljakovica	0.324966	<Null>	81.241509	81.241509	<Null>
Sumadijska	0.801632	<Null>	200.407997	200.407997	<Null>
Milice Milojkovic	0.317554	<Null>	79.388524	79.388524	<Null>
Juzna obilaznica	0.305708	<Null>	76.427124	76.427124	<Null>

215 (0 out of *2000 Selected)

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Figure 2. Attribute table

The main effort in data collection process was creating collection points database. The data was provided from field work / on-site data capture using GPS devices Garmin Colorado 300 and Trimble Juno. From these devices, data were transferred to Garmin software MapSource that contains the city map. Each collection point was attributed with non-spatial data such as unique ID, number of containers, type/capacity, photography and unloading time. The database was readjusted to Google Earth software. This software was chosen because it is free and user friendly. Current municipal vehicles routes database was also created using GPS devices, mentionedabove. Each vehicle's route was tracked separately. Database was expanded with attributes such as unique path ID, vehicle average velocity, travel time and number of emptied containers for each vehicle's waste collection and transport circuit. Vehicle's paths can also be presented and analysed trough Google Earth software. Figure 3 shows one typical vehicle route with corresponding collection points.To ensure compatibility and the access to analysis available from GIS software, databases were modified and implemented into standard GIS environment.

In the following text it will be shown how to perform the analyses and optimization of current waste collection and transport route, as well as how to estimate fuel and GHG emission savings.Figure 4 presents a typical waste collection and transport route during one working day. Presented route consists of three circuits. As described above, first circuit starts by departing from garage and driving to collection area, that is stage I. Driving inside the collection area and empting containers present stage II while stage III covers driving full truck to the landfill. The second circuit starts after truck is unloaded at landfill. At the end of the working day, the empty truck drives from landfill to the garage representing the stage IV in process of waste collection and transport. Total length of analyzed route is 59.2 kilometers, while the distance traveled by stages is shown in Figure 6.

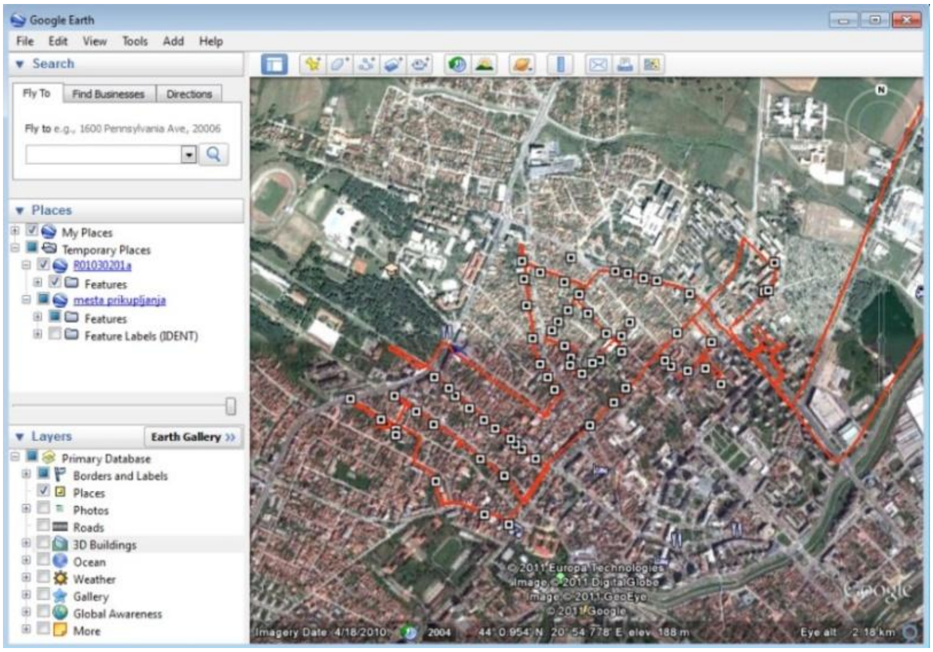

Figure 3. Route presented in Google Earth

Figure 4. Current route

Figure 5. Optimized route

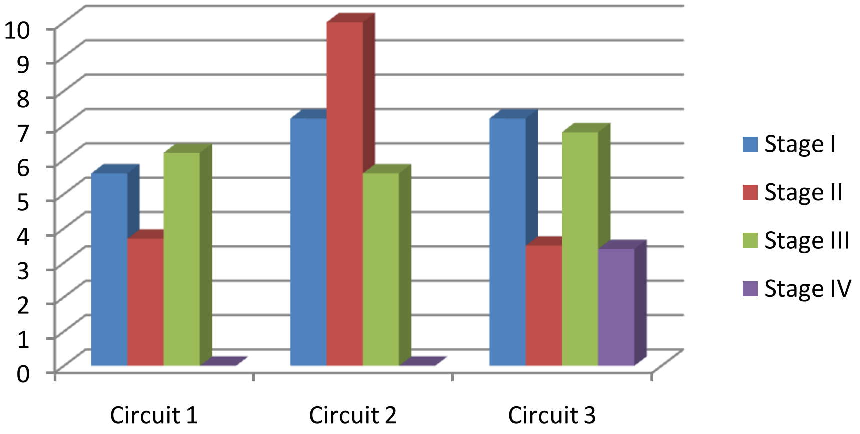

Figure 6. Distance traveled per circits (km)

Detail analyses of Figure 6 shows that collection area is far away from landfill and two-thirds of total distance traveled truck drives in stages I and III.

The data from GPS device was used to determine the average truck speed in each stage of process that is necessary for calculation of fuel consumption and GHG emission, according to methodologydescribed.

Table 3 shows details of circuit 1. The length of stage I is 5628 meters and average speed of truck is 26 km/h. In the stage III average speed decreased, in the line with expectations, caused by vehicle load. Average speed of truck by stages, used in calculations, was as follows: stage I – 28 km/h, stage II – 12 km/h, stage III – 22 km/h and stage IV – 30 km/h.

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Table 3. Detail analysis of circuit 1

From – to	Length (m)	Average speed (km/h)	Time (min:sec)	Number of containers	Idling (min:sec)
Garage – CP1 (stage I)	5628	26	12:35	2	2:02
CP1 – CP2	102	6	0:45	1	0:30
CP2 – CP3	830	21	2:21	3	2:12
...					
CP16 – CP17	220	12	1:06	2	2:10
CP17 – landfill (stage III)	6205	20	18:15		9:48

The total time of route is 5 hours and 50 minutes: 2 hours and 47 minutes of traveling time and the rest (47%) of idling time. Truck is idling during empting of containers and during unloading truck at landfill. Figure 7 shows the time spent (per container) for empting containers at each collection point. The average time required to emptyone container is 55 seconds. At few collection points, truck spent three or four times more than average time per container. Such cases occur at those collection points when containers are overfilled and there is plenty of waste alongside, so the crew needs more time to collect all the waste.

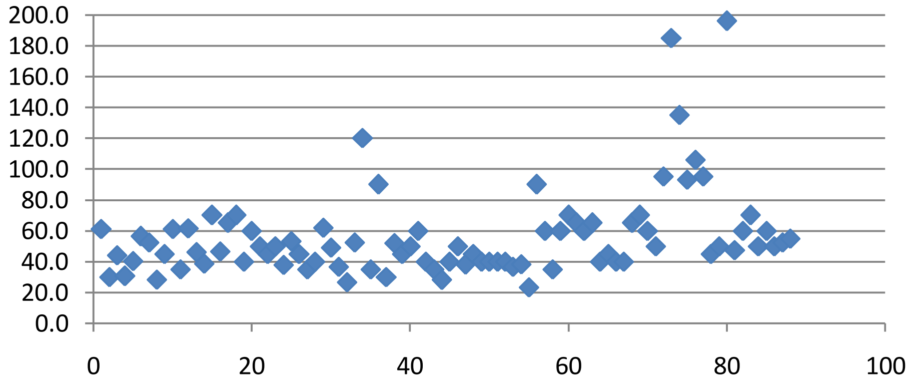

Figure 7. Time used to empty a container (s)

After all necessary data was collected; the route optimization could be made. The optimization of the selected route is consisted of two steps: as the first one detailed analysis was carried out and the second one is calculation of the shortest route distance using Network Analyst.

The analyzed route, shown in Fig. 4, has 88 collection points with 208 containers. In addition, the figure shows two characteristically segregate locations of collection points. If those two points are excluded, the total route length would be 3 kilometers shorter. Keeping in mind the fact that all containers must be emptied, collection points excluded from analyzed route would be merged to route of truck runs nearby, increasing route length for 500 meters. In such way, saving in total route length is 2.5 kilometers.

After the Network Analyst calculation was made the route's length was reduced for 6.2 kilometers. Fig. 5 shows the new route optimized for shortest distance. Total length reduction, after two steps of optimization, is 8.7 kilometers. Truck drives along this route six times per week, so saving in distance traveled is 2714.4 kilometers per year.

5. Estimation of GHG emissions in the process of waste collection and transport

Calculation of pollutants emission was made acoording to previously described procedure using equations (1)-(4). In addition to total savings in route length, Fig. 8 presents distances traveled, for each stage in process of waste collection and transport, for current and optimized route annually.

Estimated savings in pollutants emission achieved by route optimization are shown in the table 4.

Table 4. Savings in pollutants emission

Pollutant	Savings per year (kg)				
	Stage I	Stage II	Stage III	Stage IV	Sum
CO	2.3	9.9	2.4	0	14.7
CO_2	431.3	1297	446.4	0	2174.6
NO_x	5.4	19.6	5.8	0	30.9
PM	0.5	2.1	0.6	0	3.1

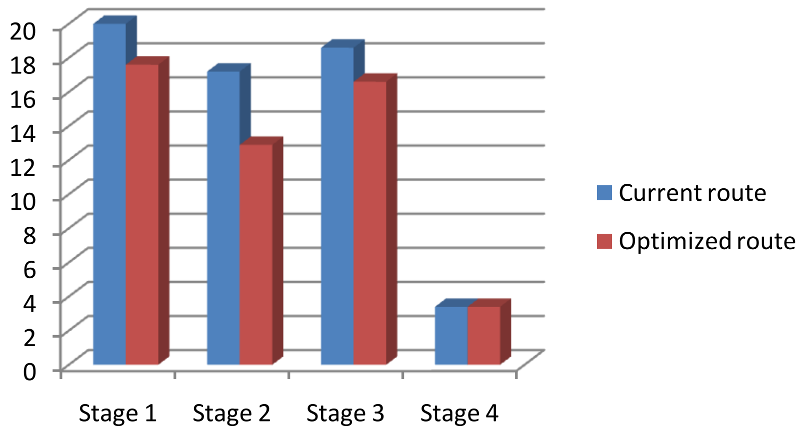

Figure 8. Distance traveled per stage for current and optimized route (km)

6. Conclusions

Waste collection and transport account for a major proportion (50% to 70%) of the total costs of waste management system. In addition, this process has a great environmental impact due to fuel combustion. Total distance traveled, in many ways, defines the amount of fuel consumed and associated pollutantsemission. This paper presented methodology for vehicle routing optimization in the process of waste collection and transport. With such optimization tool, it was possible to achieve savings of 2714.4 kilometers per year, by optimization of one route. Furthermore, reduction of pollutants emission (CO, CO_2, NOx, PM) was calculated for the optimized route and savings compared to the current was shown. Vehicle average speed for different waste collection and transport stages was taken into account. The results achieved by this approach are more accurate compared to results of typical LCA software that do not take into consideration vehicle speed as a parameter.

The nontransportation time, including time spent for loading/unloading and other idling time reached 47% of total route time for analyzed route. In addition to that, actual engine operation conditions are frequently changed due to very often vehicle acceleration/deceleration. Number of stops, time spent for empting containers and number of containers as well, have a great influence to amount of fuel spent. It is for this reason that further research will focus on optimization of collection points according to demography and improvement of waste collection frequency.

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