THE EVALUATION METHOD OF THE PROCESS OF MUNICIPAL WASTE COLLECTION

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Abstract

An intensive population growth, progressing social and economic development processes and growing urbanization of rapidly developing countries significantly translate into an increase in the amount of generated waste. At present, approx. 12 million tons of waste are produced in Poland. It should be expected that this amount will grow together with civilization progress. The amount of waste generated per person per year in Poland is 330 kg, as compared with approx. 550 kg in Germany. If these values are reached, approx. 20 million tons of waste will be produced in Poland. This makes it necessary to make rational decisions in the area of waste management in urban agglomerations. For this reason, in recent years, a growing interest has been observed in issues connected with the selection of appropriate planning strategies for waste management processes. Waste management plans assume, amongst other things, a reduction in the amount of waste intended for neutralization, encouraging recycling and creation of preferences to increase the share of recovery processes and recycling, in particular. One of the global targets involves the preparation of appropriate waste recycling strategies, which will increase its effectiveness by improved separation at the source, collection and recycling of priority waste streams. Poland's environmental policy assumes the organization of a municipal waste pre-selection, sorting and recovery system to assure that no more 50% of household waste reaches landfills. One of the most important elements of waste management system is a subsystem of planning and execution of waste collection process. Issues related to this process (determination of the areas of operation, planning vehicle routes, factors affecting the process, etc.) are widely discussed in the literature. The main goal of this article is to present method for assessing the process of planning and execution of municipal waste collection. The developed method will allow the assessment of the process of waste collection which takes into account the impact of external factors and decisions taken during the planning of the service areas. The developed method will be verified based on data from real waste management system.

Keywords: Waste management, collection of waste

1. INTRODUCTION

Modelling of waste management processes has been analysed in the literature since the late 1960s. In addition, the modeling of transport systems are widely described in the literature [eg. 9, 10, 11, 12, 13].

The literature-based study has allowed suggesting four main groups of waste management models based on the criterion of their applicability. They are:

- models of locations and selection of waste collection sites/ designing waste collection networks [eg. 2, 5, 7];
- models of planning waste collection routes [eg. 4, 6, 8];
- models of stock management processes and processing planning [eg. 1, 2, 3];
- models of support for planning waste management systems, including the use of decision support systems/expert systems, assessment tools for system functioning and case studies.

In the literature, there is a lack of methods that halps to assess the process of planning and execution of municipal waste collection. The main aim of this article is to present methods for assessing the process of planning and execution of municipal waste collection. The developed method will allow the assessment of the process of waste collection which takes into account the impact of external factors and decisions taken during the planning of the service areas. The developed method will be verified based on data from real waste management system.

2. DESCRIPTION OF THE MODEL

2.1. Assumptions of the model

The analyzed model of evaluation of the planning process and execution of municipal waste collection is based on the following assumptions. The planer assigns the selected to the vehicle specified number of waste collection points (N^{WCP}). Brigade visites in the indicated order all assigned points (i=1,2,3,... N^{WCP}). The brigade always collect only one fraction of the waste at a time. In each waste collecting points there is specified number of containers ($\mathrm{lp_i}$) with specified volume ($c_j^{p,i}$) expressed in cubic meters.

The total volume of waste collected from the i-th WCP (waste collection point) is expressed by :

$C_i = C_{i-1} + c_i\ [m^3]$, for i-th =1,2,3,..., (1)

where:

c_i - volume of waste collected from i-th WCP expressed by the following equation:

$c_i = \sum_{j=1}^{lp_i} c_j^{p,i} \cdot d^{zg}\ [m^3]$, (2)

where:

lp_i - number of containers in i-th WCP;

$c_j^{p,i}$ - volume j of container in i-th WCP;

d^{zg} - rate of volume reduction rate for the given fraction;

The vehicle is coming back to the base if:

$C_i \geq C^{dop}$ lub $i = N^{WCP}$,

where:

C^{dop} - permissible load capacity of the vehicle expressed in m^3;

N^{WCP} - number of WCP intended to be serve;

Total collecting time to i-th WCP:

$T_i = T_{i-1} + t_i^{WCP}$, dla i =1,2,3,..., (3)

where:

T_0 - the moment of the leaving of the base;

t_i^{WCP}- service time for i-th WCP expressed by equation:

$t_i^{WCP} = t_{i-1,i}^{p} + \sum_{j=1}^{lp_i} t_j^{ob,i}$, (4)

where:

lp_i - number of containers in i-th WCP;

$t_j^{ob,i}$- service time for j-th container in i-th WCP:

$t_{i-1,i}^{p}$ - driving time from i-1 to i-th WCP expressed by equation:

$$t^{p}_{i-1,i} = s_{i-1,i} \cdot t^{km}_{i,Ta}, \tag{5}$$

where:

$s_{i-1,i}$ - distance between i - 1 and i-th WCP;

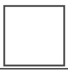
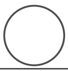
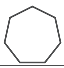
t^{km}_{i} - driving time per 1 km in the area of i-th WCP.

Waste collection points assigned to the region can be located in the areas characterized by a different type of building development: single and multi-family, uninhabited and mixed one. Different type of building development affect such factors as: the type and volume of used containers, their location and density of occurrence, the possibility of merging different collection schemes (the curbside with drop- off). **Table 1** contains the graphic descriptions of the various types of building development and **Fig. 1** shows an example of waste collection route. The part of WCP located in the area of individual types of buildings significantly affect the indicators of the collection process such as the volume of waste collected per amount of travelled kilometers (Eq. 8) and total driving time between points (Eq. 9). Therefore, it is difficult to assess the quality of the planned route only by using the following indicators. The next chapter presents the method of assessing the quality of route planning, with take into account the existence of differences in the types of buildings.

$$W_i^1 = \frac{C_i}{\sum_{j=1}^{j=i} s_{j-1,j}}, \tag{6}$$

$$W_i^2 = \frac{C_i}{\sum_{j=1}^{j=i} t^{p}_{j-1,j}}, \tag{7}$$

Table 1 Type of building development

Symbol	Type of buildings development
	Multifamily buildings
	Single-family buildings
	Uninhabited buildings
	Mixed buildings
	Distance between WCP

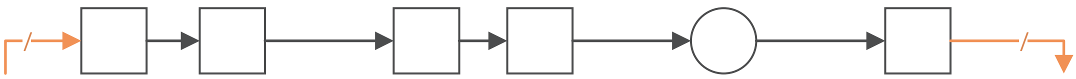


Fig. 1 Sample of waste collection route with a dominant of multifamily buildings development

2.2. The evaluation method

This chapter presents a method of evaluating the assignment of waste collection points to vehicles. We present an algorithm that describes the proposed evaluation method (**Fig. 2**). The algorithm uses the method of the center of gravity to determine level of concentration of WCP witch ware assigned to the vehicles. It takes into account the volume of waste collected from different places. It allows to assess the possibility of improving the designated area of service by identifying WCP that have a significant impact on the variation of the measured trait and should for example be moved to another area. The presented algorithm does not take into account the experience of the brigade carrying out the collection, which will be included in further work.

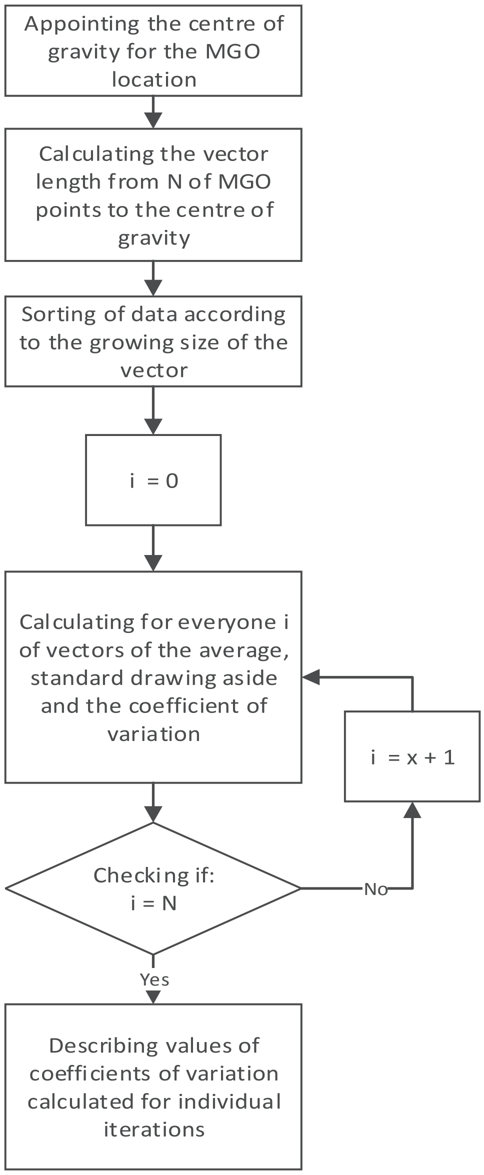


Fig. 2 The algorithm of for assessing the process of planning and execution of municipal waste collection

3. THE ANALYSIS OF COLLECTION ROUTES

For the analysis of collection routes two regions served by the same vehicle, and having a similar amount of waste streams were selected. The choice of the same brigade carrying out the route would reduce the risk of differences resulting from work experience and various techniques for waste collection. We analysed the route from the third and the seventh of July 2015. The first route was dominated by detached houses and the other by multifamily housing. The analysis does not take into account the time and distance of travel to the first point. It also excludes service time of individual sites. The results of the analysis are presented in **Table 2**. The analysis showed that single-family route is characterized by a shorter driving time. This is due to the distance between the points which were smaller than in the multi-family route. Waste collection efficiency is much greater for the multifamily route, while coefficient determining the ratio of the amount of collected waste to the total driving time is better for single-family route. The results allow to estimate, for example, the costs of servicing a given region, but do not allow to assess routes for possible improvement. In the following example, the use of the algorithm described above to evaluate both routes was placed (**Fig. 3 - Fig. 6**).

Table 2 Basic data of the WCP

	The data for single-family	Standard deviation for single-family	The data for multifamily	Standard deviation for multi-family
Number of WCP	120		106	
The total duration of the route [gg:mm:ss]	01:43:14		02:36:56	
The average distance between WCP [km]	0.1045	0.1964	0.2355	0.3825
The average driving time between WCP [s]	52.0504	78.3295	89.6762	129.3098
The total volume of all WCP [m^3]	57.9800		108.7600	
The length of the route collection [km]	12.4350		24.7260	
The total volume per distance [m^3/km]	8.6219	21.123	14.0429	19.6752
The average size of containers [m^3]	0.4831		0.7705	
The total volume per unit time schedule [m^3/h]	41.58199		33.6984	

4. CASE STUDY

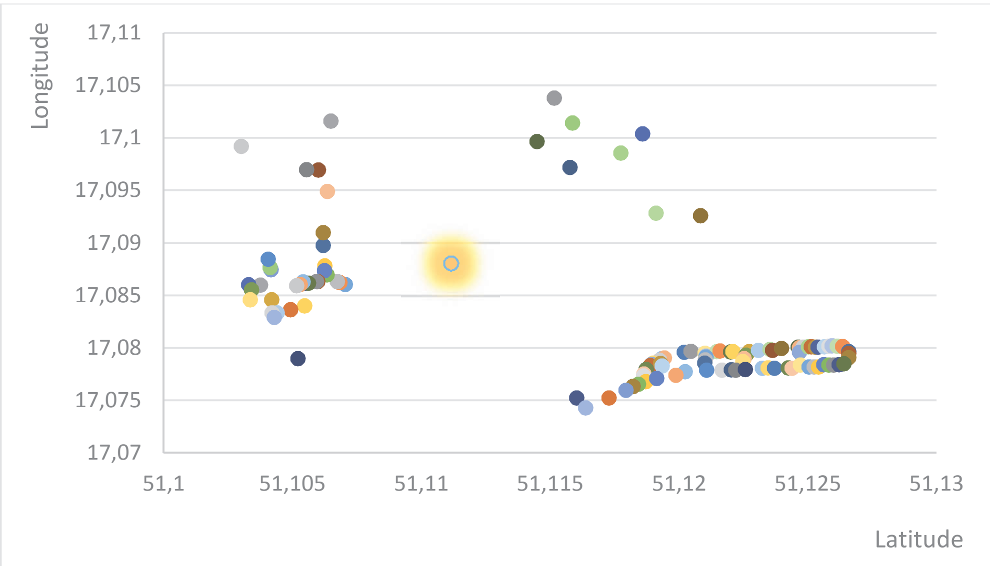


Fig. 3 Location of collection points of the center of gravity for single-family route

The proposed method assumes that the route with a higher concentration of points is qualitatively better than the route with high dispersal because it reduces the efficiency of the brigade. Another important issue is the amount of waste received at WCP. The method assumes that the route should consist of points located in close proximity, and points distant from the center of gravity should be assigned to another brigade working in the vicinity of this point. Additionally point with a relatively small volume of containers should not significantly reduce the productivity of the brigade which takes it.

In order to assess the collection route the distance of each point to their center of gravity has been calculated. The calculated distances were sorted in order from smallest to largest and the mean values, standard deviations and coefficients of variation were calculated for the increasing number of points.

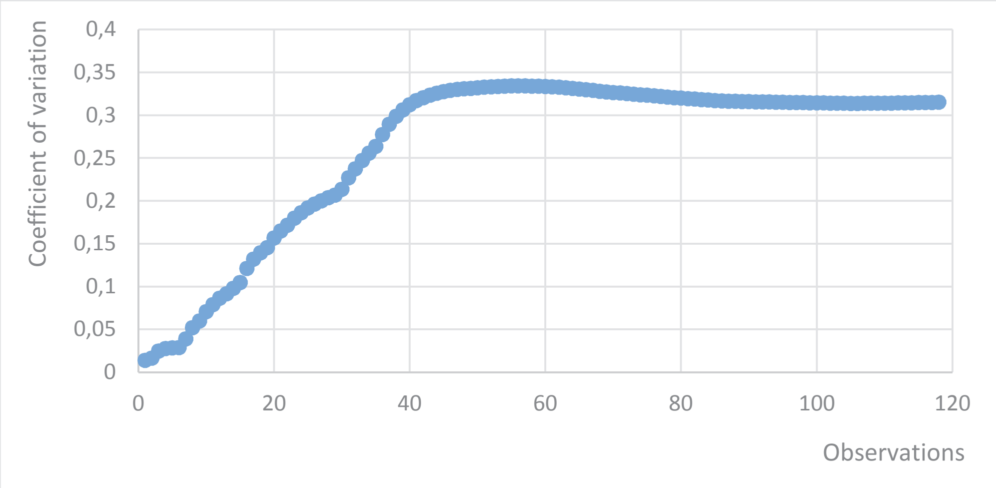


Fig. 4 The coefficient of variation growing collection points away from the center of gravity for single-family housing

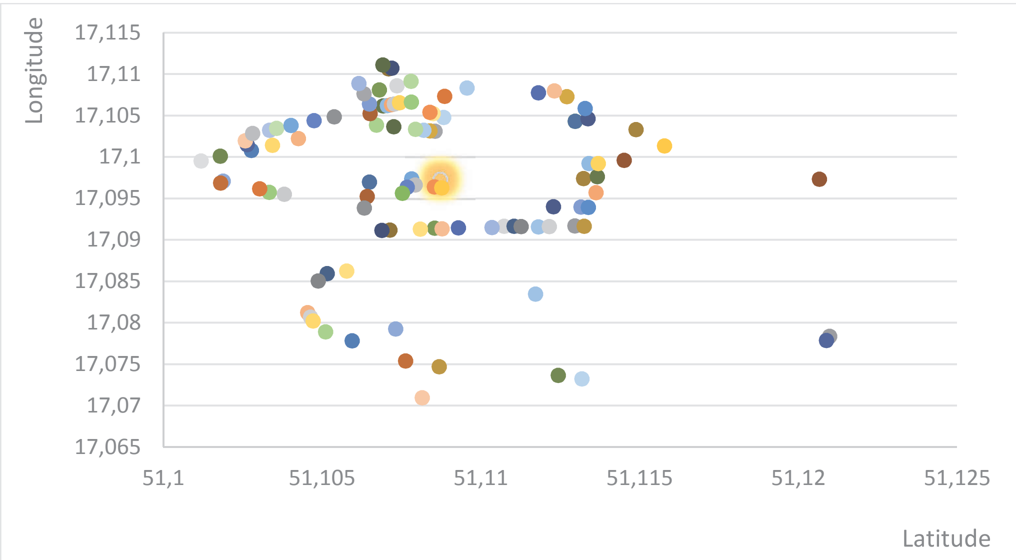


Fig. 5 Location of collection points of the center of gravity for the route multifamily

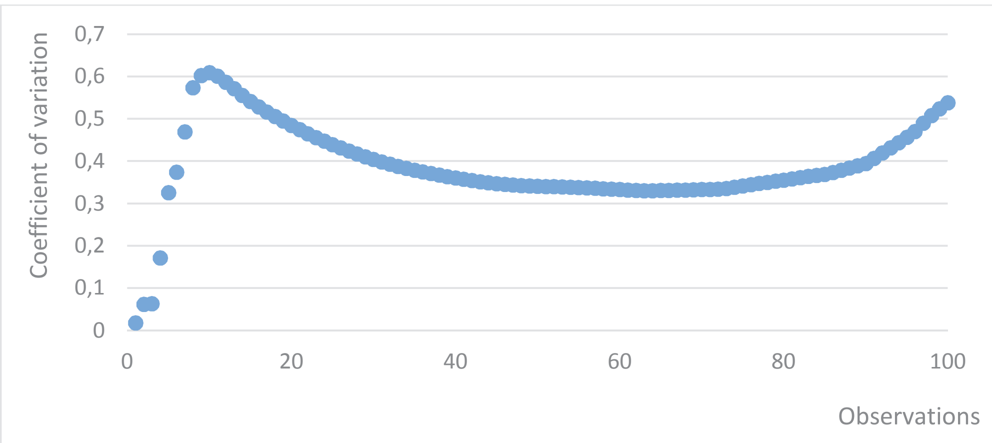


Fig. 6 The coefficient of variation growing collection points away from the center of gravity for multifamily housing

Chart 4 shows the change in the coefficient of variation for single-family route. The initial increase is due to the addition of rising values. Then after point 45 we can see its stabilization. What proves low volatility, and as a result can be assessed that the points on the route are concentrated. In contrast, in the graph No. 6 concerning multifamily housing after point 73 there is another increase of this factor. This demonstrates the significant impact of these points on the level of differentiation of the measured characteristics, long distance of points from each other, the need to travel long distances to points with a small amount of waste. This reduces the efficiency of the brigade and significantly extends the duration of the route.

5. CONCLUSION

The main goal of this paper was to present method for assessing the process of planning and execution of municipal waste collection. The developed method allow the assessment of the process of waste collection which takes into account the impact of external factors (like type of building development) and decisions taken during the planning of the service areas. The developed method was verified based on data from real waste management system. The presented method has many directions of development. Further work will take into account the experience of workers collecting waste.

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