

# The Solution of the Sorted Waste Collection Using the Methods of Multi-criteria Decision-making

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## Abstract

*This paper outlines the alternative option for the collection of sorted municipal waste using the selected methods of multi-criteria decision-making. The introductory parts include general theoretical approaches regarding the waste management. The main chapter of the paper includes obtained outcomes in regard to solve the sorted waste management in the particular area using the specific multi-criteria analysis methods. The proposed solution can help to increase the efficiency of sorted waste collection, and at the same time, reduce the waste management costs in the given area.*

## Keywords

*waste management, municipal waste, multi-criteria decision-making, WSA, TOPSIS*

## 1 Introduction

People and the environment have been affected by each other and associated to each other since ancient times. Long-term and negative effects on the environment have negative effects on an individual's life. In order to create synergistic effect between man and nature, great emphasis is placed on sustaining the natural development of man on Earth. It is important thoughtfully to dispose the wastes which arise either during production of goods or of their consumption.

Waste has been a product of human activity and accompanies humanity for a long time. The various types of waste can have various risks and degree of risk to the environment. For this purpose, there is regular evaluation of waste management for individual territorial units (Fridrich, 2009; Ministry of the Environment of the Czech Republic, 2014; Saita and Franceschelli, 2016).

In the Czech Republic, the waste monitoring is regulated by Act No. 185/2001 Coll. on waste. In accordance with waste management plans, waste management plans of individual counties and municipalities are prepared. Within the waste hierarchy, following hierarchy of waste management should be maintained (Hrebicek, 2009; Parliament of the Czech Republic, 2001; Skapa, 2005):

- a) prevention,
- b) preparing for reuse,
- c) recycling of waste
- d) other recovery operations (for example. energy recovery),
- e) disposal.

Municipal waste is the most common type of waste. Waste generation is very simple and closely related to the shopping behavior of consumers and the consumption growth. Consequently, the increase in municipal waste production means that municipalities and businesses are systematically forced to deal with the collection, transporting, sorting, recovering and disposal. Municipalities solve this state by a system of waste management which must be constantly monitored, evaluated and must respond to changes flexibly (Kuras, 2014; La Grega et al., 2010; Mika and Kucerkova, 2014).

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Increase the efficiency of waste collection and sorting system represents the objective of waste management, i.e. to achieve the highest possible production of waste which was recycled in the production (Malcekova and Simek, 2014). Currently, there is a significant increase in the sorted waste generated by increase of the total volume of mixed municipal waste, however, especially increase of the collection efficiency. Certainly, waste sorting during its creation, i.e. immediately in each household, is an important activity affecting the production of mixed municipal waste minimization. However, this activity is significantly influenced by conditions of individual households.

## 2 Waste management in the municipality Pyšely

Pyšely covers an area of three cadastral territories with a total area of 12.81 m<sup>2</sup>. Besides district, Pyšely also includes the district Nová Ves, Zaječice, Kovářovice and Borova Lhota. According to the Czech Statistical Office, Pyšely has a total of 1,851 inhabitants on December 3, 2015 (of which 887 are men and 964 women) (Czech Statistical Office, 2011). Since the late 90s of the 20th century, there has been performed the city development. This development is associated with increased construction of houses both in the city of Pyšely, and especially at the edges of the other urban areas. Population growth and production of municipal waste is related to this phenomenon (Kropacek, 2009; Kvitek, 2011).

## 3 Methods and results

Currently, Pyšely began to deal with the problem of increased quantities of waste. It wants to solve the waste management in accordance with the municipal budget as well as the satisfaction of the municipality citizens. To solve this problem, within this research study, WSA and TOPSIS methods were selected. In the first step, a utility value to each criterion determined by  $K_i$  will be assigned in order to create a sub-utility function  $u_j$ , which takes the value for the variant  $A_i$  (Cerny et al., 1980; Dostal et al., 2005). See Eq. (1).

$$u_j(A_i) = u_{ij}; i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (1)$$

The definition scope of this function is represented by the interval between the best and the worst value of the relevant criteria. The interval  $h_j, l_j$  represents the range of functional values. This method is suitable for quantitative criteria. The method assumes a linear dependence of utility on the values of criteria, whereby the value 0 is assigned to the worst value of the  $j$ -th criterion (denoted as  $d_j$ ) and the utility 1 is assigned to the best value (denoted as  $h_j$ ). For the utility  $u_{ij}$  of value  $y_{ij}$ , is applied (Eq. (2)) (Fiala et al., 1997):

$$u_{ij} = \frac{y_{ij} - d_j}{h_j - d_j}; i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (2)$$

TOPSIS method is based on a variant selection which is closest to the ideal variant and farthest from the basal variant.

Maximizing character of all criteria is assumed. If all the criteria are not maximizing, it is necessary to convert them to maximizing. TOPSIS method procedure can be described as follows (Jurkovic and Sosedova, 2013; Kampf et al., 2016; Lendel and Jankovic, 2011; Luczak and Wysocki, 2011):

Step 1: to convert of all the criteria to maximizing,

Step 2: to create a normalized criteria matrix  $R = (r_{ij})$  according to the Eq. (3):

$$r_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^m y_{ij}^2}}; i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (3)$$

Step 3: columns of matrix  $R$  represent the vectors unit standard,

Step 4: to convert the criteria matrix  $R$  to normalized criteria matrix  $Z$ , so that each column of the matrix  $R$  is multiplied by the weight of corresponding criteria, according to the Eq. (4):

$$z_{ij} = w_j r_{ij} \quad (4)$$

Step 5: to create an ideal variant by using elements of the matrix  $Z (h_1, h_2, \dots, h_n)$  and basal variant  $(d_1, d_2, \dots, d_n)$ , where

$$h_j = \max_i z_{ij}; j = 1, 2, \dots, n \quad (5)$$

$$d_j = \min_i z_{ij}; j = 1, 2, \dots, n \quad (6)$$

Step 6: the distance from the ideal variant is calculated by (Eq. (7)):

$$d_i^+ = \sqrt{\sum_{j=1}^n (z_{ij} - h_j)^2}; i = 1, 2, \dots, m \quad (7)$$

Step 7: the distance from the basal variant is calculated by (Eq. (8)):

$$d_i^- = \sqrt{\sum_{j=1}^n (z_{ij} - d_j)^2}; i = 1, 2, \dots, m \quad (8)$$

Step 8: relative indicator of variants distance from the basal variant is calculated by (Eq. (9)):

$$c_i = \frac{d_i^-}{d_i^+ + d_i^-}; i = 1, 2, \dots, m \quad (9)$$

Variants will be organized by non-growing values of  $c_i$ .

### 3.1 Criteria identification

First step consists in the criteria identification according to the above described methodology (procedure). Criteria list was compiled based on an assessment of the current state of waste management and survey that was performed among residents of Pyšely municipality. The individual criteria are summarized below (Vetrakova et al., 2013):

1. Procurement costs.
2. Operating costs.
3. Ownership of the devices for the waste management.
4. Speed of alternatives deployment.

5. Specific worker for handling with waste.
6. Yield of municipal waste components.
7. Information technologies.
8. Availability of collection points.
9. The number of containers for sorting municipal waste.
10. Possibility to reduce the fee for waste.
11. Frequency of sorted municipal waste collection.

Evaluation of above mentioned criteria was carried out by representatives of the municipality. This assessment represents a “municipality opinion” and individual scoring criteria were sorted from the most significant to insignificant as follows:

11. Operating costs.
10. Possibility to reduce the fee for waste.
9. Procurement costs.
8. Yield of municipal waste components.
7. Frequency of sorted municipal waste collection.
6. Speed of alternatives deployment.
5. The number of containers for sorting municipal waste.
4. Specific worker for handling with waste.
3. Availability of collection points.
2. Ownership of the devices for the waste management.
1. Information technologies.

### 3.2 Creating the alternatives

The next step was to propose changes which would possibly improve waste management in the selected location and convenience of population within the waste sorting. There are many possibilities of increasing the yield of recyclable components. For the city Pyšely, selected acceptable alternatives are as follows:

- alternative no. 1 - extension of number of existing collection points by new containers,
- alternative no. 2 - extension of number of existing collection points by new containers and establishing new collection points,
- alternative no. 3 - maintaining the current state,
- alternative no. 4 - maintaining the current state and establishing a bag collection,
- alternative no. 5 - extension of number of existing collection points by new containers and establishing a bag collection,
- alternative no. 6 - maintaining the current state, establishing new collection points and establishing a bag collection.

After processing the previous steps, it is possible to proceed to create a criteria matrix which is shown in Table 1. Criteria matrix consists of a table where the columns are formed from alternatives and rows are formed from individual evaluation criteria. The various alternatives are evaluated according to evaluation scale from 1 to 5.

**Table 1** Criteria matrix

Criteria	A1	A2	A3	A4	A5	A6	Weight of criteria
Procurement costs	0	0	0	5	5	5	9
Operating costs	5	5	5	0	0	0	11
Ownership of containers	0	0	0	5	5	5	2
Speed of alternatives deployment	0	0	0	5	5	5	6
Specific worker	0	0	0	5	5	5	4
Yield of components	3	5	0	3	3	5	8
IT equipment	0	0	0	5	5	5	1
Availability of places	0	5	0	5	5	5	3
Number of containers	3	4	1	5	5	5	5
Fee reduction	0	0	0	5	5	5	10
Frequency of collection	0	0	0	5	5	5	7

### 3.3 WSA method

On the basis of criteria matrix, method WSA, the weighted sum approach, which is based on the utility detection, is implemented. Benefits can be measured on a linear scale of evaluation (Lizbetin et al., 2015). Calculation of this method includes 5 steps (Gasparik and Zitricky, 2010; Houska, 2012):

The first step is to create criteria matrix including an indication of minimum criteria, which are shown in Table 2.

**Table 2** Marking the minimization criteria in criteria matrix

Criteria	A1	A2	A3	A4	A5	A6	Weight of criteria
<b>Procurement costs</b>	0	0	0	5	5	5	9
<b>Operating costs</b>	5	5	5	0	0	0	11
<b>Ownership of containers</b>	0	0	0	5	5	5	2
<b>Speed of alternatives deployment</b>	0	0	0	5	5	5	6
<b>Specific worker</b>	0	0	0	5	5	5	4
Yield of components	3	5	0	3	3	5	8
IT equipment	0	0	0	5	5	5	1
Availability of places	0	5	0	5	5	5	3
Number of containers	3	4	1	5	5	5	5
Fee reduction	5	5	5	0	0	0	10
Frequency of collection	5	5	5	0	0	0	7

The next step is to transfer the minimizing matrix to maximizing matrix and find the best and the worst alternative for each criterion. These values are summarized in Table 3.

Next step is to calculate the benefits of each alternative according to the equation for maximization criterion. Calculation of the effectiveness of the various alternatives is presented in Table 5.

**Table 3** Criteria matrix after conversion to maximizing criteria, including finding the best and worst alternatives for each criterion

Criteria	A1	A2	A3	A4	A5	A6	Weight of criteria
Procurement costs	5	5	5	0	0	0	9
Operating costs	0	0	0	5	5	5	11
Ownership of containers	5	5	5	0	0	0	2
Speed of alternatives deployment	5	5	5	0	0	0	6
Specific worker	5	5	5	0	0	0	4
Yield of components	3	5	0	3	3	5	8
IT equipment	5	5	5	0	0	0	1
Availability of places	0	5	0	5	5	5	3
Number of containers	3	4	1	5	5	5	5
Fee reduction	0	0	0	5	5	5	10
Frequency of collection	0	0	0	5	5	5	7

The last and final step, in the application of this method, is to calculate the total utility for each alternative. The resulting values are summarized in Table 4.

According to the final calculation by the method WSA, alternative 6 is the most optimal variant which is “maintaining the current state, establishing new collection points and establishing a bag collection “.

### 3.4 TOPSIS method

Now, we apply TOPSIS method for the same problem. The method is based on the principle of minimizing the distance from the ideal variant, i.e. principle of maximizing the distance from the worst variant

Similarly to the WSA method, the calculation by this method includes several steps which describe the methodology of this research (Harrison et al., 2015; Rao et al., 2015):

- the compilation of criteria matrix with indicating the minimum criteria,
- the conversion of minimization criteria to maximization criteria, as shown in Table 8.

**Table 4** Calculation of total utility for each alternative

Criteria	A1	A2	A3	A4	A5	A6	Weight of criteria
Procurement costs	0.1364	0.1364	0.1364	0.0000	0.0000	0.0000	0.1364
Operating costs	0.0000	0.0000	0.0000	0.1667	0.1667	0.1667	0.1667
Ownership of containers	0.0303	0.0303	0.0303	0.0000	0.0000	0.0000	0.0303
Speed of alternatives deployment	0.0909	0.0909	0.0909	0.0000	0.0000	0.0000	0.0909
Specific worker	0.0606	0.0606	0.0606	0.0000	0.0000	0.0000	0.0606
Yield of components	0.0727	0.1212	0.0000	0.0727	0.0727	0.1212	0.1212
IT equipment	0.0152	0.0152	0.0152	0.0000	0.0000	0.0000	0.0152
Availability of places	0.0000	0.0455	0.0000	0.0455	0.0455	0.0455	0.0455
Number of containers	0.0379	0.0569	0.0000	0.0758	0.0758	0.0758	0.0758
Fee reduction	0.0000	0.0000	0.0000	0.1515	0.1515	0.1515	0.1515
Frequency of collection	0.0000	0.0000	0.0000	0.1061	0.1061	0.1061	0.1061
Sum	0.4440	0.5570	0.3334	0.6183	0.6183	0.6668	-

**Table 5** Calculation of utility for each alternative

Criteria	A1	A2	A3	A4	A5	A6	Weight of criteria
Procurement costs	1	1	1	0	0	0	0.1364
Operating costs	0	0	0	1	1	1	0.1667
Ownership of containers	1	1	1	0	0	0	0.0303
Speed of alternatives deployment	1	1	1	0	0	0	0.0909
Specific worker	1	1	1	0	0	0	0.0606
Yield of components	0.6	1	0	0.6	0.6	1	0.1212
IT equipment	1	1	1	0	0	0	0.0152
Availability of places	0	1	0	1	1	1	0.0455
Number of containers	0.5	0.8	0	1	1	1	0.0758
Fee reduction	0	0	0	1	1	1	0.1515
Frequency of collection	0	0	0	1	1	1	0.1061

**Table 6** Transformed matrix

Criteria	A1	A2	A3	A4	A5	A6	Weight of criteria
Procurement costs	0.5774	0.5774	0.5774	0.0000	0.0000	0.0000	0.1364
Operating costs	0.0000	0.0000	0.0000	0.5774	0.5774	0.5774	0.1667
Ownership of containers	0.5774	0.5774	0.5774	0.0000	0.0000	0.0000	0.0303
Speed of alternatives deployment	0.5774	0.5774	0.5774	0.0000	0.0000	0.0000	0.0909
Specific worker	0.5774	0.5774	0.5774	0.0000	0.0000	0.0000	0.0606
Yield of components	0.3419	0.5698	0.0000	0.3419	0.3419	0.5698	0.1212
IT equipment	0.5774	0.5774	0.5774	0.0000	0.0000	0.0000	0.0152
Availability of places	0.0000	0.5000	0.0000	0.5000	0.5000	0.5000	0.0455
Number of containers	0.2985	0.3980	0.0995	0.4975	0.4975	0.4975	0.0758
Fee reduction	0.0000	0.0000	0.0000	0.5774	0.5774	0.5774	0.1515
Frequency of collection	0.0000	0.0000	0.0000	0.5774	0.5774	0.5774	0.1061

**Table 7** Criteria matrix

Criteria	A1	A2	A3	A4	A5	A6	Weight of criteria
Procurement costs	0.5774	0.5774	0.5774	0.0000	0.0000	0.0000	0.1364
Operating costs	0.0000	0.0000	0.0000	0.5774	0.5774	0.5774	0.1667
Ownership of containers	0.5774	0.5774	0.5774	0.0000	0.0000	0.0000	0.0303
Speed of alternatives deployment	0.5774	0.5774	0.5774	0.0000	0.0000	0.0000	0.0909
Specific worker	0.5774	0.5774	0.5774	0.0000	0.0000	0.0000	0.0606
Yield of components	0.3419	0.5698	0.0000	0.3419	0.3419	0.5698	0.1212
IT equipment	0.5774	0.5774	0.5774	0.0000	0.0000	0.0000	0.0152
Availability of places	0.0000	0.5000	0.0000	0.5000	0.5000	0.5000	0.0455
Number of containers	0.2985	0.3980	0.0995	0.4975	0.4975	0.4975	0.0758
Fee reduction	0.0000	0.0000	0.0000	0.5774	0.5774	0.5774	0.1515
Frequency of collection	0.0000	0.0000	0.0000	0.5774	0.5774	0.5774	0.1061

**Table 8** Criteria matrix after conversion to maximizing criteria

Criteria	A1	A2	A3	A4	A5	A6	Weight of criteria
Procurement costs	5	5	5	0	0	0	9
Operating costs	0	0	0	5	5	5	11
Ownership of containers	5	5	5	0	0	0	2
Speed of alternatives deployment	5	5	5	0	0	0	6
Specific worker	5	5	5	0	0	0	4
Yield of components	3	5	0	3	3	5	8
IT equipment	5	5	5	0	0	0	1
Availability of places	0	5	0	5	5	5	3
Number of containers	3	4	1	5	5	5	5
Fee reduction	0	0	0	5	5	5	10
Frequency of collection	0	0	0	5	5	5	7

The next step is to transform the matrix. This transformation is performed according to step 2 and the results are interpreted in Table 6.

The following step is to transfer the criteria matrix  $R$  to normalized criteria matrix  $Z$  according to step 4. This transfer is shown in Table 7.

Now, according to the methodology, the best and worst alternative for each criterion according to step 5 are determined. The next step of the method is to perform the calculation of distance from the best variant according to step 6 and from the worst variant according to step 7. In the application of this method, a final step is to calculate indicators of variants of distance from the worst variant according to step 8, which is shown in Table 9.

We will assess the various alternatives according to resulting values. The alternative with the highest resulting value is the most appropriate alternative. Based on the resulting values, TOPSIS method considers the alternative no. 6 “maintaining the current state, establishing new collection points and establishing a bag collection” as the most appropriate alternative.

**Table 9** TOPSIS method

Criteria	A1	A2	A3	A4	A5	A6	Weight of criteria
Procurement costs	0.0787	0.0787	0.0787	0.0000	0.0000	0.0000	0.0787
Operating costs	0.0000	0.0000	0.0000	0.0962	0.0962	0.0962	0.0962
Ownership of containers	0.0175	0.0175	0.0175	0.0000	0.0000	0.0000	0.0175
Speed of alternatives deployment	0.0525	0.0525	0.0525	0.0000	0.0000	0.0000	0.0525
Specific worker	0.0350	0.0350	0.0350	0.0000	0.0000	0.0000	0.0350
Yield of components	0.0414	0.0691	0.0000	0.0414	0.0414	0.0691	0.0691
IT equipment	0.0087	0.0087	0.0087	0.0000	0.0000	0.0000	0.0087
Availability of places	0.0000	0.0227	0.0000	0.0227	0.0227	0.0227	0.0227
Number of containers	0.0226	0.0302	0.0075	0.0377	0.0377	0.0377	0.0377
Fee reduction	0.0000	0.0000	0.0000	0.0875	0.0875	0.0875	0.0875
Frequency of collection	0.0000	0.0000	0.0000	0.0612	0.0612	0.0612	0.0612

## 4 Conclusion

To propose suitable alternatives for increase the effectiveness of separate collection together with reducing the cost of waste management in Pyšely, partial results from the analysis of the system current state and sorting of municipal waste in Pyšely were used. Also, the results of a questionnaire survey among the residents of the municipality were used. Based on these analyzes, alternatives, which were then evaluated using the methods of multi-criteria decision-making, were proposed.

According to obtained and processed results, solution, in order to optimize the waste management, for the councilors of municipality Pyšely was proposed to consider these measures in different segments of the waste management in this municipality and evaluate the proposed alternative of optimization. It means to create new collection points in the proposed areas of the municipality and repair or replace existing damaged containers as well as establish a bag collection (minimizing the paper, paperboard and plastic packaging) to supplement the existing collection and delivery system.

After this alternative approval, it is necessary to introduce it gradually in practice and implement these changes into the directives of the municipality. This alternative represents especially the financial savings for the municipality, since it could reduce the frequency of municipal waste collection after the establishing a bag collection, which represents the holder of considerable costs of the waste management due to the type of buildings in the municipality.

On the contrary to a bag collection, the municipality can expect an increase in yield of municipal waste components, particularly paper and plastics. Higher yield also brings greater rewards from collective systems. At last but not least, this alternative is very similar to requirements of residents who participated in the questionnaire survey and expressed their opinions and suggestions for improvement.

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