Design of Centralized Collection Points for Plastic Waste Within Reverse Logistics Chain – A Case Study for the Conditions of Waste in the Slovak Republic

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Abstract **– Wastes and effective waste management are critical issues in all countries due to massive production and consumption volumes. One of the possible ways to create an effective waste management model is by applying the philosophy of reverse logistics and its processes to the waste management solution. The paper presents the result of a case study oriented to allocating centralized collection points of plastic wastes in the condition of Slovak Republic (SR). The presented results of the case study are a part of general research in the field of waste management according to the processes and activities of reverse logistics realized by the authors of the paper, which analyze and solve the entire problem of waste management in the condition of SR and creates a base for the further solution of the problematic issues of waste management.**

Keywords **– Logistics, reverse logistics, centralized collection point, waste.**

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1. Introduction

Waste is a useless result of consumption that society wants or intends to eliminate and dispose of. The amount of waste began to multiply with the production of consumer goods, packaging, industrial activities, etc. Forecasts of waste creation say that waste production will increase year-on-year.

This trend is characteristic of Slovakia and the world, where the amount of produced waste is expected to increase due to the growing population, urbanization, and increased consumption. Although some initiatives and campaigns try to minimize the amount of waste and improve its processing, the trend of growing waste will continue. Therefore, it is important to continue to support initiatives and solutions to minimize waste and to process it better.

At the beginning of the 21st century, new technological and environmental procedures, a new understanding of waste meaning, and law changes at international and national levels brought new and innovative solutions for several issues of waste and its commodities. It is also very important to emphasize that the membership of the Slovak Republic in the European Union (EU) affected the entire waste management process due to law changes, the implementation of several international and European law directives and several valuable guidelines in the waste management process. Slovakian waste management is based on a waste prevention program and several legislative guidelines. During the following period, reducing the amount of waste should be governed by the Waste Prevention Program of the Slovak Republic for the years 2019-2025, prepared by the Ministry of the Environment by § 7 of Act No. 79/2015 Coll. about waste.

This program is based on the experience gained while preparing and implementing the previous waste prevention program. The current program is also based on the ongoing evaluation of the fulfilment of the goals and measures of the last program. This program also considers the current situation and developments in the EU regarding the circular economy application process. The principle of this program is the transition "from a linear model of economic growth" ("extract - produce - distribute - use - throw away") to a complex, dynamic, and closed model and thus defined for the development of efficient use of resources and sustainable growth [1].

Therefore, it is very important to develop waste management, not only for the Slovak Republic but for all countries, and to determine, to a greater extent, the methods of collection, sorting, and various forms of waste processing. The solved research issue was focused on several areas of waste management and its current state, where is visible the possibility of placing the principles and idea of reverse logistics as a tool for creating a closed waste model with the highest possible rate of material processing of waste and obtaining secondary raw materials from waste.

2. Application of Reverse Logistics for Waste Management - Literature Review

Globalization, rapid technological advances, and production and consumption have caused efforts to improve efficiency in the supply chain of all industries and social lives to solve the problem of created waste. Therefore, it is possible to monitor the continuous promotion of practices oriented to recycling to ensure constant growth with the help of reducing the consumption of natural resources and environmental burdens [2].

One possible way to understand and solve waste flow is reverse logistics. Reverse logistics processes create a way for companies to become more environmentally efficient through recycling, reusing, and reducing the materials used [3].

In the past, reverse logistics was often viewed as the unwanted stepchild of supply chain management. The reason was a necessary cost for companies, regulatory compliance issues or a "green" initiative.

Several important researchers in this area of logistics formed the base of reverse logistics. For example, Rogers D. *et al.* [4] defined reverse logistics as a process of planning, implementing, and controlling an effective and efficient flow of raw material, in-process inventory, and finished goods but also specified the direction of this flow from the point of consumption to the end of origin. Stock, J.R. *et al.* [5] presented a reverse logistics definition by the Council of Logistics Management.

According to this, reverse logistics has a role in production returns, reduction of sources and materials, recycling, reuse, waste disposal, etc.

Fleischmann M. *et al.* [6] oriented their research activity in reverse logistics to classify product recovery networks based on the main differences. They separated this reverse logistics network into three parts: bulk recycling network, assembled-product remanufacturing network and reusable network.

Thierry, M.C. *et al.* [7] presented in their research strategic issue in product recovery management and according to reverse logistics, they emphasized eight types of possible options of recovery or disposal in the theory of reverse logistics: direct reuse/resale, repair, refurbishing, remanufacturing, cannibalization, recycling, incineration, and disposal in the landfill.

However, it is possible to say that reverse logistics presents a strategic activity that can enhance supply chain competitiveness over the long term [8]. Reverse logistics is a part of supply chain management processes, also called returns management. This consists of all activities related to returns flow, reverse logistics, and effective gatekeeping—the focus of reverse logistics shifts to getting products back from customers rather than moving products to customers [8]. The entire management of return flows induced by the various forms of reuse of products and materials in industrial production processes has received growing attention throughout the last decade [9]. This decade is characterized by a significant increase in product recovery activities and interest in the sustainability of supply chains and logistics networks [10]. At this point, it is also essential to talk about increasing consumers' inclination toward environmental sustainability based on green management of production and consumption, legal pressure, and a possible economic benefit for producers in the idea of integrating recovery activities into the production processes [10]. As mentioned, for today's condition, it must be emphasized that once the resource reduction option has been exhausted, companies should attempt to maximize reuse, followed by recycling. Waste disposal should also be the last option [11].

A significant part of all these activities is the process of collection, which is an inseparable part of reverse logistics. Each recovery option involves the collection, followed by a combination of inspection, selection, sortation and re-processing or recovery [12]. Authors of study [13] dealt with the problem of collection centre location based on reverse logistics network design.

They determined the area and capacities of the collection centres, the amounts of products from the point of generation to the collection centres, and from collection centres to companies. They defined three important problems: minimization of costs, ensuring equity among different companies and providing a steady flow of products to each company.

In their study, Kaynak R. *et al.* [14] emphasized the role of collection points in reverse logistics. They identified barriers and schemas provided by the collection points for reverse logistics. They defined five significant aspects that affected the possible location of centralized collection points in the reverse logistics chain: coordination and cooperation, centralization, consolidation, 3rd party RL collaboration, and integration.

Budak, A. and Ustundag, A. [15] present a very interesting view of the solution of reverse logistics optimization for waste collection and disposal in Turkey for health institutions. The authors designed a multiperiod and multitype product waste reverse logistics network for an effective collection and disposal system.

The paper presents a partial output of the research intention of authors and cooperating institutions. The main goal of the several-year research activity is to design and effectively reverse the material flow of waste for the condition of Slovakia, as is presented for examples in the following papers [16], [17], [18], [19]. Researchers, during their research activities, tried to find the optimal solution for the sortation, collection, and re-processing of waste according to the legislative conditions in Slovakia. One of the parts of the research was an idea based on reverse logistics – centralized collection centres for waste in the entire area of Slovakia. The paper presents the output of this partial aim of the research, with a focus on plastic waste. Also, it was based on the issue that one of the problematic parts of waste management is SR, which is the way of waste centralization. A possible solution is to use one of the important ideas of reverse logistics: a centralized collection point (CCP) for waste. The paper presents the allocation of a centralized collection point for plastic waste in the condition of the Slovak Republic and its possibilities according to the law. It also presents a new way of plastic collection based on the backup of cans and PET bottles applied in Slovakia from January 2022 [20].

3. Case Study – Design of a Centralized Collection Point for Plastic Waste in the Conditions of Slovakia

The amount of waste is increasing, but monitoring the trend of waste recovery is possible. However, what is alarming for SR is the amount of waste landfilling, which is one of the leading places in the EU [21]. Table 1 presents the state of waste management in SR and selected waste management methods. The huge problem of SR was the landfilling of waste due to low environmental innovation and the pure meaning of people about the issue of waste recycling. However, it is important to emphasize that this idea is gradually changing, which is also due to the transformation of the law.

The main goal of the activities in the Slovak Republic is to reduce the amount of landfilled waste gradually and to focus on possible ways of recycling and reprocessing. However, in Slovakia, the problem is still waste collection; although separate waste collection is introduced in the Slovak Republic and EU countries, due to low environmental awareness or maturity of society. Figure 1 presents the development of waste collection state during years 2009-2018.

Table 1. Production of wastes in SR [22]

Year	2009	2020	2022
Wastes in total [t]	6 777 713,3	2 434 039,5	10 593 124,3
Material recycling [t]	1 675 028,4	586 087,6	5 244 318,1
Incineration with energy recovery [t]	155 470,1	187 795,3	202 788,2
Reclamation of organic substances and composting [t]	592 423,6	476 846,8	996 186,5
Other recovery [t]	910 399,8	84,8	100 706,2
Landfilling [t]	2 670 604,0	1 177 944,3	1 720 030,8
Incineration without energy recovery [t]	not available	95,4	8 648,6
Other disposal [t]	28 911,0	308,6	342 917,4
Other treatment [t]	524 709,4	655,9	1 977 528,6

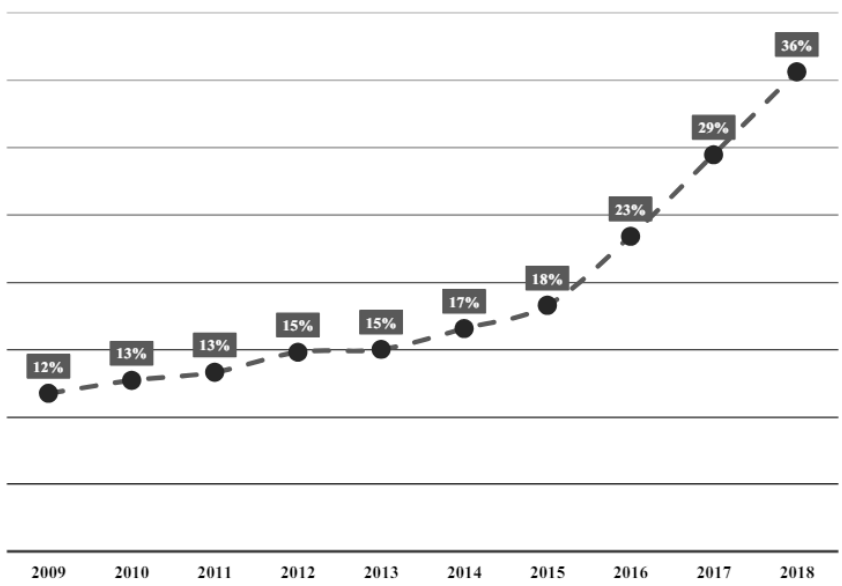

Figure 1. Development of waste collection during the years 2009-2018 [22]

A significant impulse to increase the amount of separated plastic waste collection occurred after the introduction of backup as one of the economic tools of reverse logistics for waste collection. However, despite the introduction of backup, the current collection of collected plastic waste is quite chaotic. Therefore, it is important to direct these waste flows to central places so that the subsequent flow of waste for further processing is simplified and with the least possible additional costs. The objective of this section of the paper is to study a real case and also analyse the applicability of multi-criteria decision analysis for the possible solution of the selected issue of reverse logistics – allocation of centralized collection points.

The solution of CCP allocation was based on the decision-making method (DMM) and analytical hierarchical process (AHP), which belong to multi-criteria decision analysis (MCDA). It is possible to say that MCDA presents a prescriptive theory and associated models and tools that help in various contexts, such as environment, engineering, business, health, etc [23]. Decision-making is a study of identifying and choosing alternatives according to the decision-maker's values and preferences. The decision-making means that there are several choices to be considered. Identifying as many of these alternatives as possible and choosing an option that best fits the determined objectives, goals, values, etc., is important. Decision-making has to have the exact steps, starting with identifying the decision maker in the decision, reducing the possible disagreement about problem definition, requirements, goals and criteria [24]. In the last decade it is possible to monitor increased using of MCDA in environmental applications [25], [26], [27], [28], [29]. The most important part of MCDA is the structure of the objectives hierarchy and weights assigned to the specified objectives [30]. The hierarchy presents the base for evaluation, and also affects the comparison of alternatives. The key part of MCDA is the relative importance of the objectives which is captured by assigning weights to the objectives.

3.1. Input Data of the Case Study

The study was oriented to the collection point in each district of Slovakia (the country has eight districts). The newly presented results show the allocation of a centralized collection point for the district of Prešov in the east part of the country. This district is divided into 13 regions. Each area presents an alternative for the allocation of CCP. The selected criteria for the methods were number of inhabitants (population of the research area), amount of recycled waste (plastic) for the selected time period, area, road (due to the fact of worse road condition in the research area). The idea of CCP allocation is reducing of the costs for transportation of the selected type of waste. The realization of the study was based on the steps presented by the Figure 2 and Table 2 presents the input data to the study and for evaluation of alternatives.

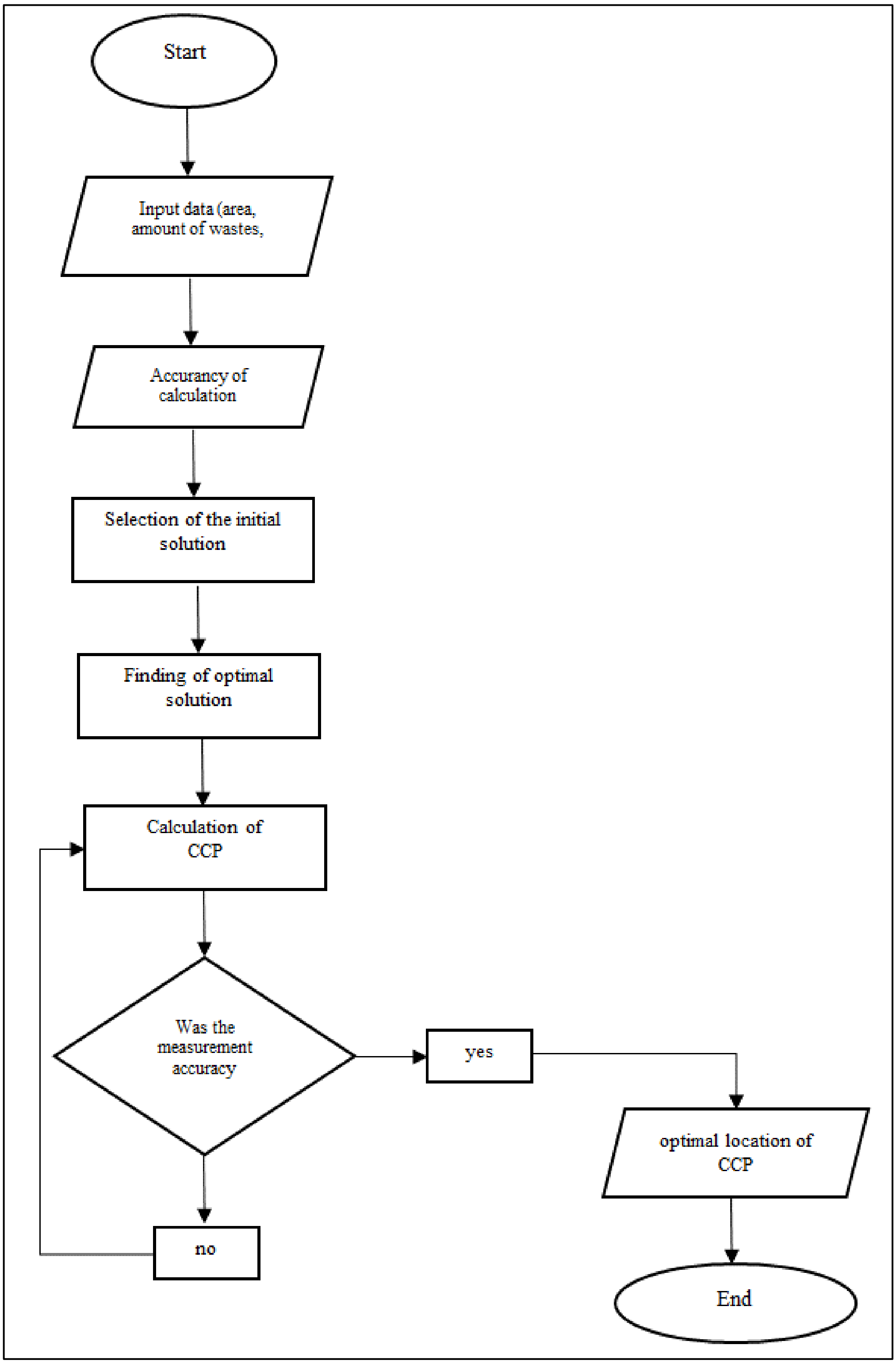

Figure 2. Flow chart of the case study solution

Table 2. Input data for evaluation of alternatives [22]

Criteria	Alternatives												
	BJ (A1)	HE (A2)	KK (A3)	LE (A4)	ML (A5)	PP (A6)	PO (A7)	SB (A8)	SV (A9)	SL (A10)	SP (A11)	SK (A12)	VT (A13)
Population (K1) [number of inhabitants]	77806	64329	66795	32584	12170	104481	165613	56329	38752	51710	20789	33208	78488
Amount of wastes (K2) [t]	28,86	1158,58	48,18	61,62	9,53	3309,49	548,57	276,71	681,13	271,47	49,88	8,813	168,78
Area (K3) [km^2]	936	754	839	357	427	1112	934	484	805	624	389	550	769
Roads (K4) highways [km]/classic roads of the 1st class [km]	0 /47,354	0 /22,707	0 /30,77	31,707 /38,668	0/0	35,653 /94,403	43,501 /86,953	0 /27,250	0 /39,536	0 /72,64	0 /22,42	0 /67,962	0/80,289

4. Results and Discussion

The result of this case study presents the solution of CPP allocation by using DMM and AHP as a simple and low-cost method for decision-making.

4.1. Results of Decision Method Application

As mentioned, this method compares several possible solution variants according to the different determined criteria.

The first step in this method is the determination of weights for criteria. Table 3 presents the decision matrix of DMM. Weights determine the importance of criteria in terms of the set goals. The process continues quantitatively evaluating how the selected criteria meet the variants. A comparison of 2 criteria points to 1 - the most important criterion, 0 – less important criterion, 0,5 – equally important criterion. The result is the variant with the most points.

Table 3. Decision matrix of DMM

Criterion	Weights	**Alternatives**												
		BJ (A1)	HE (A2)	KK (A3)	LE (A4)	ML (A5)	PP (A6)	PO (A7)	SB (A8)	SV (A9)	SL (A10)	SP (A11)	SK (A12)	VT (A13)
Population (K1)	5	6	5	5	4	2	8	9	5	4	5	3	4	6
Amount of recycling wastes (K2)	6	3	7	3	3	2	9	5	5	5	5	3	2	4
Area (K3)	5	8	6	7	3	4	8	8	4	7	5	3	4	6
Roads (K4)	4	5	3	4	8	1	8	8	3	4	6	3	6	6

The calculation of this method determined the weights of the criteria. The first step was a pairwise comparison of the evaluation criteria. A pairwise comparison of alternatives according to criteria 1 – 4 is in steps 2 – 5. The conclusion of this method is the multiplication of weights by the point values of alternatives. Alternative 6 – Poprad received the most points based on the set criteria. This area is the largest and most important characteristic of this area's road condition. Table 4, Table 5, Table 6 present the procedure of calculation of the DMM according to the selected criteria.

Table 4. Step 6 Multiplying of weights by the point values of alternatives A1 - A5

Criterion	Weights	Alternatives									
		BJ (A1)		HE (A2)		KK (A3)		LE (A4)		ML (A5)	
Population (K1)	0,25	0,122	0,031	0,083	0,021	0,083	0,021	0,038	0,010	0,000	0,000
Amount of recycling wastes (K2)	0,4	0,045	0,018	0,141	0,056	0,045	0,018	0,045	0,018	0,006	0,002
Area (K3)	0,25	0,141	0,035	0,083	0,021	0,109	0,027	0,006	0,002	0,038	0,010
Roads (K4)	0,1	0,077	0,008	0,026	0,003	0,141	0,006	0,141	0,014	0,000	0,000
Weighted sum	1		0,091		0,101	0,058	0,072		0,043		0,012
Order			5.		3.		8.		9.		12.

Table 5. Step 6 Multiplying of weights by the point values of alternatives A6 - A9

Criterion	Weights	Alternatives							
		PP (A6)		PO (A7)		SB (A8)		SV (A9)	
Population (K1)	0,25	0,141	0,035	0,154	0,039	0,083	0,021	0,038	0,010
Amount of recycling wastes (K2)	0,4	0,154	0,062	0,109	0,044	0,109	0,044	0,109	0,044
Area (K3)	0,25	0,141	0,035	0,141	0,035	0,038	0,010	0,109	0,027
Roads (K4)	0,1	0,141	0,014	0,141	0,014	0,026	0,003	0,058	0,006
Weighted sum	1		0,146		0,131		0,076		0,086
Order			1.		2.		7.		6.

Table 6. Step 6 Multiplying of weights by the point values of alternatives A10-A13

Criterion	Weights	Alternatives							
		SL (A10)		SP (A11)		SK (A12)		VT (A13)	
Population (K1)	0,25	0,083	0,021	0,013	0,003	0,038	0,010	0,122	0,031
Amount of recycling wastes (K2)	0,4	0,109	0,044	0,045	0,018	0,006	0,002	0,077	0,031
Area (K3)	0,25	0,064	0,016	0,006	0,002	0,038	0,010	0,083	0,021
Roads (K4)	0,1	0,103	0,010	0,026	0,003	0,103	0,010	0,103	0,010
Weighted sum	1		0,091		0,025		0,032		0,092
Order			5.		11.		10.		4.

4.2. Result of AHP Application

This method constantly compares two criteria; their evaluation is presented in Saaty`s matrix. Point evaluation is offered by Table 7.

Table 7. Pair-wise comparison scale for AHP preferences [31]

Numerical rating	Verbal judgments of preferences
1	Equally preferred
2	Equally to moderately
3	Moderately preferred
4	Moderately to strongly
	Strongly preferred
6	Strongly to very strongly
7	Very strongly preferred
8	Very strongly to extremely
9	Extremely preferred

The value corresponding to comparing the criterion in the row with the criterion in the column is written to the upper triangular matrix. An inverse value is written to the bottom part of the triangular matrix if the second criterion is more important. Values are gradually counted in the columns and then divided into the values in the cell with the sum belonging to the column. The standardized values of weights are obtained by counting the values in the rows and dividing them by the entire sum of values in the matrix. The calculation of total utility for the variants the following formula calculates Uj:

$$U_j = \sum_{i=1}^{n} a_i * u_{ij} \quad (1)$$

[31]

Where a_i is the standardized weight of the *i* criterion, u_{ij} is the utility of the j variant according to the *i* criterion, *n* is the number of defined criteria, and *m* is the number of evaluated variants [31].

The procedure for the determination of partial utilities is like determining weights. The criterion that best meets the given alternative gets the most points. An alternative with the maximum number of points is the most suitable solution to the research issue. The selected criteria are *K1* number of inhabitants, *K2* number of recycled wastes (plastics), *K3* area and *K4* roads. Table 8 presents the point evaluation of critera and Table 9 presents the calculation of standardized weights. The calculation of the total utility is presented in the Table 10.

Table 8. Step 1 Point evaluation of criteria

Criterion	A	B	C	D
A	0,00	0,33	1,00	3,00
B	3,00	0,00	3,00	5,00
C	1,00	0,33	0,00	3,00
D	0,33	0,20	0,33	0,00
∑	4,33	0,87	4,33	11,00

Table 9. Step 2 Calculation of standardized weights

Criterion	A	B	C	D	∑	Standardized weights
A	0,00	0,38	0,23	0,27	0,89	0,22
B	0,69	0,00	0,69	0,45	1,84	0,46
C	0,23	0,38	0,00	0,27	0,89	0,22
D	0,08	0,23	0,08	0,00	0,38	0,10
∑	1,00	1,00	1,00	1,00	4,00	1,00

Table 10. Calculation of the total utility

Criteria	**K1**		**K2**		**K3**		**K4**		∑	**Order**
Weights a_i	**0,22**		**0,46**		**0,22**		**0,1**			
	u_{ij}	$a_i * u_{ij}$	u_{ij}	$a_i * u_{ij}$	u_{ij}	$a_i * u_{ij}$	u_{ij}	$a_i * u_{ij}$		
BJ	0,09	0,021	0,02	0,011	0,18	0,040	0,05	0,005	0,077	4.
HE	0,05	0,011	0,20	0,090	0,06	0,013	0,02	0,002	0,117	3.
JJ	0,05	0,011	0,02	0,011	0,10	0,023	0,03	0,003	0,048	8.
LE	0,02	0,005	0,02	0,011	0,01	0,003	0,21	0,021	0,040	9.
ML	0,01	0,003	0,01	0,006	0,02	0,004	0,01	0,001	0,014	12.
PP	0,22	0,048	0,32	0,145	0,18	0,040	0,19	0,019	0,253	1.
PO	0,29	0,064	0,08	0,037	0,18	0,040	0,19	0,019	0,160	2.
SB	0,05	0,011	0,08	0,037	0,02	0,004	0,02	0,002	0,054	7.
SV	0,03	0,006	0,08	0,037	0,10	0,023	0,03	0,003	0,068	5.
SL	0,05	0,011	0,08	0,037	0,04	0,008	0,08	0,008	0,063	6.
SP	0,02	0,003	0,02	0,011	0,01	0,003	0,02	0,002	0,019	11.
SK	0,03	0,006	0,01	0,006	0,02	0,004	0,08	0,008	0,024	10.
VT	0,09	0,021	0,05	0,021	0,06	0,013	0,08	0,008	0,063	6.
∑ U_j	1	0,220	1	0,460	1	0,220	1	0,100		

Because the most suitable solution is the alternative with maximum points in this method, the most appropriate way for allocating the centralized collection point is the area of the Poprad district (alternative No 6).

5. Conclusion

The aim of this study was twofold. The first aim was to present a very important part of reverse logistics in the field of waste and focus on the collection process on the base of centralized collection points. As it was mentioned collection of waste is still a huge challenge for waste management. It must be emphasized that authors in their research activity deal with research of reverse logistics, solution of its processes in the condition in the field of waste. Their research activity is separated to all legislatively determined wastes in Slovakia. The paper presents the current state of waste management in Slovakia and the importance of creation of a closed waste model with the highest possible rate of material processing and obtaining of secondary raw materials from wastes. It is not possible to create it without effective solution of waste collection. On the base of theory of reverse logistics the tool for it can be a centralized collection point. The paper presents the results of the case study aimed at the proposal of allocation of centralized collection point of plastics wastes for the conditions of Slovakia. The second aim of the study was present a possible use of MCDA as a suitable tool for evaluation and proposal of centralized collection point for wastes.

The allocation of CCP for plastics wastes was solved by the method of DMM and AHP. According to these methods the best suitable alternative is the alternative No 6 district of Poprad. It is the largest area of the Prešov region, with the area of 1 112km^2, also it is the third largest city in eastern Slovakia. This district has a favorable traffic location on the road of international meaning E50, highway D1 and also the main railway at the direction Košice to Bratislava with connection to Ukraine and Czech Republic.

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