Computer Techniques as Innovative Tool Supporting Decision Making Process Within Waste Collection in Cities

Marianna Jacyna, Jolanta Żak
Warsaw University of Technology, Poland

One of the priorities in modern concept of urban management is municipal waste management as a part of disposal or reverse logistics. Solving waste management problems as transport problems should embrace conditions of sustainable development. The paper presents aspects of organization of reverse logistics in Warsaw agglomeration including current situation and scale of the task. The selected aspects of multicriteria decision support are described and important elements of defining criteria preferences are pointed. The basis of MAJA method and rank method applied in SuperChoose software are presented. Application is a computer tool supporting decision making within selecting alternative ways of organization waste collection in urban area. Paper includes calculation example for real data from Warsaw agglomeration.
Keywords: reverse logistics, disposal logistics, transport, the Mazovia province, Warsaw agglomeration.

1. INTRODUCTION

The important area of interest for modern logistics is serving urban agglomerations. In general city logistics system can be defined as a set of elements linked by specific relations that realizes processes and actions typical for logistics of highly urbanized areas. These activities are related to: passenger transport (public transport, mass and individual transport), freight transport (supply, distribution, removal), warehousing and order-picking, utilities supply (gas, electric, water), solid wastes disposal (removal and neutralization), telecommunication network [4], [5], [10], [15], [20]. Serving such a wide range of customers raises issues of coordination of material flows and accompanying information flows to meet client expectations about the price, and quality of offered services. The more that improvement of supplies quality through increasing the number of vehicles on infrastructure has negative impact on quality of life and condition of communication system.

The waste and sludge logistics is important area of research [1], [7], [8], [10], [11]. Utilization and neutralization of wastes generated in agglomeration takes its toll on whole transportation system of the city. It requires proper logistics chains linked to the existing freight transport systems. The main goals of reverse logistics are [8], [10], [11]:

- lowering costs and improving recycling processes,
- saving natural resources, eliminating environmental pollution resulting from actions taken within waste logistics [1], [14].

Figure 1 presents basic chain of solid waste removal from the urban area.

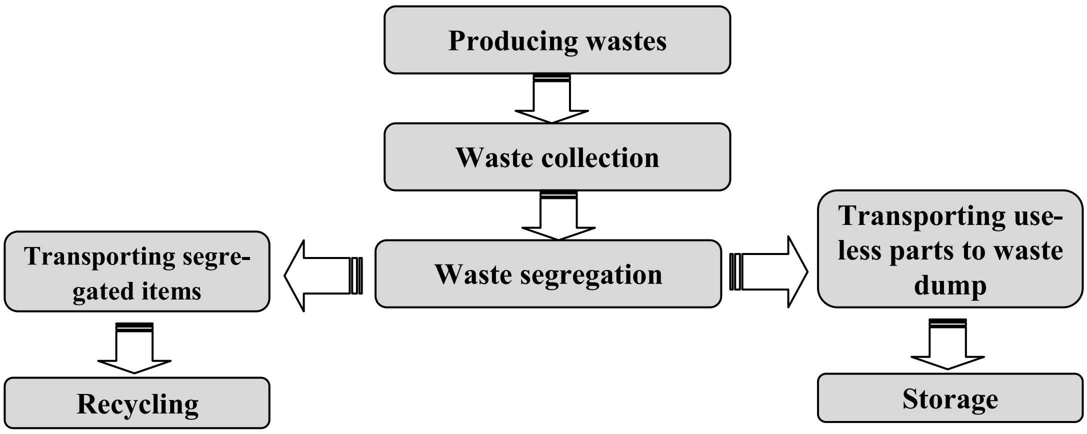

Fig. 1. General structure of waste removal chain.
Source: based on [8].

It should be noted that designing waste collection system is a process requiring from designer taking good decisions to constitute proper solution. These decisions are often taken intuitively and based on experience and knowledge acquired previously by decision maker. Specialized software is then required to help this process if different interests of various participants have to be taken into account. In addition, the decision-maker usually has to deal with [10]:

- large number of possible variants of solution;
- complicated decision-making situation;
- possibilities of high profits or large loss (i.e. financial);
- scale of decision problem.

Making informed decisions is the key to obtaining optimal solutions equivalent to selecting variants providing maximum benefit at minimum cost. Therefore computer technologies are increasingly used while the number of factors influencing the choice of investment project variant is growing. Particular attention is being given to the choice of variants in complex projects where one needs to take into account the interests of many subjects. The use of appropriate information systems significantly improves the quality of decisions.

2. THE PROBLEM OF REVERSE LOGISTICS AND WASTE

2.1. THE NATURE AND OBJECTIVES OF REVERSE LOGISTICS

Possibility of recovering used materials when natural resources are depleting is crucial for the further development of societies. At the same time increasing amount of municipal waste becomes a great problem, especially in industrialized countries. Consumers require from manufacturers minimizing the negative impact of their production on the environment. One solution to the problem of waste neutralization is the segregation and re-use of eligible contents (recycling) [1], [8], [12].

According to the definition of the EU Commission wastes are *substances or objects of the categories set out in the Annex, which the holder discards or intends to remove or their disposal is required under national law. Removing is defined as all operations that do not lead to the possibility of resource recovery, recycling, reclamation, direct re-use as secondary raw materials or alternative uses*. In the Accession Treaty, Poland committed itself to the specific limits of recovery (including recycling) of packaging waste and reducing the amount of biodegradable municipal waste to be deposited in accordance with approved schedule (see Table 1).

Table 1. The data on the limits of packaging waste recovery

No.	Date of implementation	The percentage reduction in the weight of the waste produced in 1995
1.	31.12.2010	75% of total weight of waste
2.	31.12.2013	50% of total weight of waste
3.	31.12.2020	35% of total weight of waste

Source: [10]

As a result, in October 2010, the Polish government adopted guidelines for the amendment of the Act on maintaining cleanliness and order in the municipalities [10]. According to the amendment the municipality shall assume the responsibilities of property owners in the management of municipal waste. At the same time the municipal controlling is strengthened so that they monitor the actions taken by both property owners and companies collecting waste.

Minimizing of the harmful effects of waste management on the environment, and minimizing the amount of waste stored for long-term is crucial for protection of natural environment. Coordination of related logistics processes is therefore organizational, economic and technical multi-aspect issue. The logistics purpose is to integrate within space and time the municipal waste flows, and to provide desired environment condition while costs are minimal [1], [7], [11].

In the literature ([1], [8], [12]) much attention is paid to a so-called hierarchy of waste recovery according to which re-use of products is the main goal. Authors point out that products are re-used for different purposes, not always compatible with the original application. Re-use of particular product should be performed in a way ensuring that all components return to relevant companies.

Recycling as a way of recovering value from waste is reduced to create an efficient system for sorting, storage and collection of used goods. According to that recycling is done by companies collecting and transporting municipal waste, sorting waste, and by recycling plants [10]. The main and most important goal of reverse logistics is complete removal of waste from the market on the one hand, and minimizing the total amount of recyclable materials disposed to the landfills on the other hand. The third thing is securing existing landfills.

Proper organization of reverse logistics is a complex and multifaceted decision problem. Decisions have influence on the quality of life, economic efficiency of companies, and natural environment. Thus, it becomes necessary to identify methods and tools for decision support embracing innovative ideas to select appropriate patterns of organization of waste collection – especially in urban areas.

2.2. LEGAL REGULATIONS ON THE RECYCLING OF RECYCABLE MATERIALS

Poland committed compliance with Article 80 of the Treaty, which obliges to prevent deterioration of natural environment. According to the Treaty, the cost of waste disposing is incurred by the entrepreneur who produces it; thereby the actions tending to cleaner production are initiated. The most important EU legislation on waste logistics are various directives ([24], [25], [26], [28], [30], [32], [33]). Consequently the EU promotes strategy of five principles of waste management including:

1. preventing waste production through appropriate technologies and products,
2. recycling,
3. optimal final disposal,
4. provisions for transportation,
5. corrective actions in the natural environment.

The issue of waste disposal is regulated in Poland by law [11], [34], [37] including the most recent Act dated 14 December 2012 on waste, which inducts the EU Directive 2008/98/EC [34]. The Act determines means to protect environment, human life and health, and to minimize the impact on the environment and human health of production and management of solid waste. The assumptions of the Act are intended to implement the principles sustainable development according to the EU directives.

Current law introduces new definitions, such as waste vendor (dealer), waste broker, and prevention of waste production. In addition it classifies waste and states how to deal with it. It describes a number of new laws, including developments highlighting the need of prevention of new waste production and to facilitate their re-use. Under new law the database of products, packages and waste management (so-called BDO) is developed to replace the existing Integrated Waste System[1].

The storage of waste is defined as temporary storage of waste received from the manufacturer or when the manufacturer is forced to store it temporarily until it is shipped to a landfill or to the processing facility. Waste directed for disposal cannot be stored for more than a year, while wastes

[1] *http://www.ekoinfo.pl/ustawa-o-odpadach-podpisana-przez-prezydenta-uniqueidjXNs7lB4Pu1cRBOGrZTdQpMV6VvNgA3l/*

destined for neutralization no longer than three years. Temporarily storage requires appropriate license. Despite the fact that the entrepreneur is neither the producer nor recycler, he is obliged to obtain such permission according to law. When entrepreneur wants only to store waste temporarily he must have a legal title to the ground, but when waste storage is a business more stringent requirements must by complied with institutions involved in the storage and treatment of waste are required to determine the location of the temporary storage. These include: an integrated system of waste production, decisions approving hazardous waste management program, business license or permit for waste neutralization and license for the collection and transportation of waste.

Another license required in the area of reverse logistics is a license for transport of waste. The permit is issued for less than 10 years and is issued by proper municipal jurisdiction. If the trader carries on transport of hazardous waste necessary documents must be complete.

3. CHANGE IN APPROACH TO WASTE SELECTION ON THE EXAMPLE OF WARSAW AGGLOMERATION

The main objective in waste management is preventing generating waste through new methods of production and serving, and using new types of materials. If this is not possible, harmful effects that waste have on life, health and the environment at every stage of the product life [22], [35] must be reduced. Neutralization should be subject only to such waste for which re-use or recovery is not possible.

According to GUS (General Statistics Office), the Mazovia province leads both in the quantity of waste generated (361 kg of municipal waste per capita in 2011 – the average in Poland was 315 kg), and in the amount of waste collected, with average of 275 kg while for whole Poland it was 255 kg. The total quantity of waste within the Warsaw metropolitan area is one of the basic data needed to develop an organization of waste flows. The expected amount of waste generated in Warsaw in the next years is presented in Table 2.

Table 2. Estimated amount of municipal waste generated in Warsaw till 2020 [Mg]

		Estimated amount of municipal waste in Warsaw till 2020 [Mg]			**Requirements for treatment [% of waste]**			
No.	**Type of municipal waste**	**Year**			**Treatment**	**Year**		
		2011	**2015**	**2020**		**2011**	**2015**	**2020**
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1	Biodegradable	356760	364910	373280	acceptable disposal by landfill	63	46	35
2	Biomass	28030	28340	28540	required level of recovery through composting	50	50	50
3	Packages	201380	212060	224840	required level of recovery	-	60	60
4	Outsizes	31090	32060	33100	required level of segregation	55	70	70
5	Demolition waste	45350	48650	52770	required level of segregation	45	60	60
6	Hazardous waste	8610	8880	9170	required level of segregation	57	80	80
Total		**753730**	**761350**	**769400**				

Source: own analysis based on [7].

The GUS report on Waste Management shows that in 2011 nearly 50% of collected waste was segregated; resulting in 71,3 thousand tons of recovered materials (5,5% of the total waste). In the Mazovia 13,9% of collected municipal waste was recycled (average in Poland 11,4%). As shown in Figure 3 the amount of materials collected selectively each year increases in relation to the previous year. Figure 4 presents the trend line for the amount of waste collected selectively.

Analysis of the directional factors of obtained functions shows that the amount of waste collected selectively generally increased nearly twice as fast as from households. R-squares for that function are 0.94 - 0.96, so actual values differ little from the estimates for the trend line.

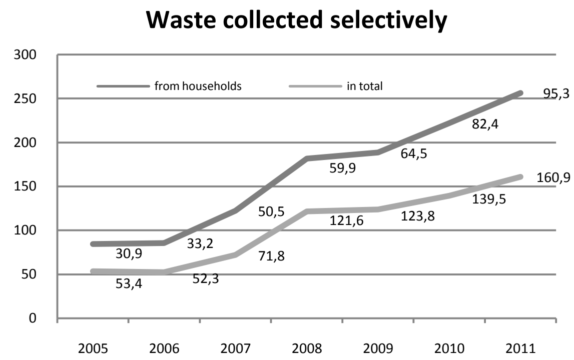

Fig. 3. Waste collected selectively [thous. t].
Source: own analysis based on [7].

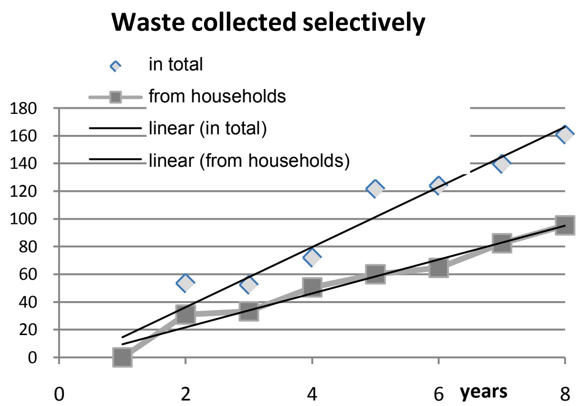

Fig. 4. The trend of amount of waste collected selectively [thous. t].
Source: own analysis based on [7]

In the Mazovia re-use of both mixed and separately collected waste is possible through [23]:

- municipal waste incinerator (no of operational: 1)
- sorting plants for separately collected waste (no of operational: 30)
- sorting plants for mixed waste (no of operational: 25)
- outsized waste disassembly lines (no of operational: 4)
- composting plants for organic fraction of waste derived from mixed municipal waste, segregated organic waste, biodegradable waste, biomass (no of operational: 19)
- MBP (mechanical and biological production) (no of operational: 17).

Warsaw agglomeration is highly urbanized area which includes Warsaw and numerous towns and villages of the Mazovia. This is a typical example of monocentric agglomeration dominated by central site (Warsaw). Officially the Warsaw agglomeration boundaries were set in the Spatial Development Plan of Mazovia voivodship (Resolution of the Parliament of the Mazovia Province on June 7, 2004). Table 3 summarizes the requirements relating to the management of selected types of waste.

Table 3. Requirements for the management of selected types of waste

No	Type of waste	Treatment	Year		
			2011	2015	2020
	2	3	4	5	6
1	Biodegradable	acceptable disposal by landfill	63	46	35
2	Outsizes	required level of segregation	55	70	70
3	Demolition waste	required level of segregation	45	60	60
4	Hazardous waste	required level of segregation	57	80	80
5	Biomass	required level of recovery through composting	50	50	50
6	Packages	required level of recovery	-	60	60
		required level of recycling	-	55	55

Source: own analysis based on [7]

Achieving the levels of waste re-use from Table 3 requires systemic solutions. At present the collection of waste from Warsaw is organized on free-market principles. Municipal waste is collected from producers on the basis of agreements with companies having licenses to collect and transfer waste to the recovery or disposal. There is a strong need to create sorting and transfer points to optimize waste flow.

4. COMPUTER AIDED ORGANIZATION OF WASTE COLLECTION

4.1. MULTICRITERIA METHODS OF DECISION SUPPORT

Making right investment decisions is a key element of businesses operation. The decision making process is complex and requires different criteria of evaluation. A multitude of options and criteria can lead to confusion, and in turn to financial losses. Therefore, it is necessary to use computer applications supporting this process.

Multi-criteria decision support methods are used to evaluate and create a ranking of alternative decisions which constitute the elements of a discrete and countable set of feasible solutions. These methods are only to assist, and to find specific conditions to take right decisions, from which the final – the best one is selected [9], [16], [17].

There are many tools supporting multi-criteria decision making (MCDM) or multi-attribute decision making (MADM) [6], and two general approaches to the problem. First one is multi-criteria decision analysis (MCDA, or multi-attribute decision analysis MADA) relating to the assessment of results of potential decisions. Many theoretical and practical aspects of MCDA are discussed in the work of J. Figueira [6]. The second approach refers to multi-objective decision making (MODM) and uses mathematical programming methods to generate variants of considered solutions described by a set of values of relevant parameters.

One of the multi-criteria methods of decision support is ELECTRE III allowing to assess and rank a finite set of *i*-th alternative solutions, through a coherent family of *j*-th criteria. This method is a representative of group of methods based on outranking relation characteristic for so called European school of decision-making by Roy and Vanderpooten [16]. Calculation procedure can be divided into five stages:

1. construction (or pre-selection) of variants and criteria selection,
2. modeling decision-maker preferences according to various criteria (weighting individual criteria – k_j, and defining thresholds: q_j, p_j, v_j),
3. construction value outranking relation – S,
4. ordering variants on the basis of outranking relation – creating two complete pre-orders: the ascending and descending,
5. building the final ranking as a intersection of the two complete pre-orders.

A similar method of ranking alternatives is MAJA described in [9]. MAJA was originally used to evaluate the traffic distribution on transport network according to: adjustment of transport infrastructure to the tasks, technical limitations of transport network, economic constraints, environmental and social interests, and different perspectives of transport process participants.

The method bases on using a detailed assessment of traffic distribution variants and factors of relative importance of involved criteria. As a consequence, it allows choosing the best option of spreading the traffic into network. It can be used successfully in other areas of supported decision making. The numerical aspect of the method is reduced to the calculations of compliance and non-compliance factors for all criteria, and using the dominance relationships to determine non-dominated variant of the solution as the best one. The method comprises:

1. establishing a set of variants;
2. determining the vector of parameters for calculating assessment indicators for each variant,
3. defining a set of sub-criteria for variants evaluation,
4. normalization of variants ratings,
5. assigning weights to each sub-criterion,
6. constructing a matrixes of compliance and non-compliance of criteria ratings,
7. calculation of indicators of compliance and non-compliance criteria ratings,
8. setting thresholds of compliance and non-compliance,
9. comparison of all possible pairs of variants using thresholds of compliance and non-compliance and non-compliance and compliance indicators,
10. creating a family of graphs based on different thresholds of non-compliance and compliance.

An important element of the process is adjusting compliance and non-compliance thresholds. These thresholds operate as a "sieve" to reject solutions not meeting the conditions. Thresholds of compliance and non-compliance are used to construct incidence matrix which allows plotting a domination graph. This means that the final choice of the best variant is made on the basis of a graph, in which not-dominated vertices are selected.

Ranking method is relatively simple to use but very effective. It is based on summing standardized parameters and sorting options from the best. It is possible to identify clearly the best solutions and to cluster solutions into different categories, depending on the assessment. This method is effective for complex computational problems.

The MCDA methods involve a number of general questions related to not only the choice of the method, but also the expectations, multicriteria nature of decisions and the restriction of objectivity [16].

Making the right decisions must be preceded by understanding three basic concepts that characterize them:

- decision alternative (decision variant, decision making) – variants of decision are considered in terms of universal features given as a set of parameters of known values. Then they are treated simply as objects, which have no assigned feasibility or applicability attribute. When a particular variant becomes valuable in term of taken decision, assigning these attributes is necessary,
- criterion – utility evaluating a specific aspect of the decision variant,
- measuring scale – assigns scores to the variants. This assessment allows comparing the quality of different decision variants in view of the particular aspect.

To aggregate the partial preferences related to the impact of the criteria considered separately, MCDA methods use a mechanism of multi-criteria aggregation procedure, (MCAP). Basically, two basic approaches to the preferences aggregating can be distinguished:

- the concept of the synthetical criterion – means individual assessment of the variants according to particular, separately considered criteria, and then constructing the overall ranking of alternatives. The appropriate mathematical formula must be used. Often the character of the formula enables recognizing the impact of uncertainty of information,
- the concept of synthesis of relational system of preferences – used to compare the relationship between pairs of variants. Relationships are determined on a base of overall characteristic of variants derived for a set of criteria. Variants assessment includes dependencies between criteria. This concept differs from above in that there is a possibility to include into analysis of discrimination thresholds and the veto thresholds, and – what is important – broader list of relations between variants. This significantly facilitates the recognition of quality aspect, hard to measure nature of available information and outcome of variants evaluation.

4.2. OPTIMIZATION OF WASTE COLLECTION ORGANIZATION

The main factor influencing assessment of waste collection system is time. Time of serving particular areas of the city depends on many factors. Urban agglomeration is not uniform area in terms of building structure, density of population, and transportation network, which affects the serving time of specific areas and customers. The analysis revealed the following factors affecting serving time of in different areas in city agglomeration:

- differentiated density of population in areas influences the location of garbage containers. The higher the density, the more containers is located in the smaller area,
- the way that loader has to overcome with container is dependent on local building restrictions,
- the speed limits impeding vehicles mobility, and the fact that some of the streets are one-way which results in longer travels.

According the research presented in [18] it was shown that efficiency of waste collection system depends mostly on proper routing. Routes optimization affects:

- service time of areas,
- total distance traveled by vehicles serving the area.

Area serving time consists of the time of containers handling and total travel time between the starting point and the various points in the s-th area for k-th vehicle. The area serving time is given as:

$$t_{or} = \sum_{s \in S} n_s w + \sum_{s \in S} \sum_{k \in K} t^k_{prs} \qquad (1)$$

where:

t_{or} – total serving time of s-th area,

w – handling time of single container,

n_s – number of containers to be handled in s-th area,

t^k_{prs} – total travel time between starting point and places of collection in s-th area by k-th vehicle.

A model of traveling salesman problem is closest to the specifics of route optimization for waste collection. The schedule of distribution minimizing length of routes of all vehicles should be found then [3]. To determine the optimal organization of waste collection routes a computer program "Route optimization" available on the

Warsaw University of Technology, Faculty of Transport was used. Program requires the following data:

- the set of waste collection places,
- the volume of waste in collection points to be picked,
- the number and loading capacity of vehicles,
- distances between all collection points and between waste sorting plant in the area.
- traveling times on all distances.

Other criteria affecting the assessment of waste collection system are:

- total transportation costs,
- unit cost of transport,
- length of routes,
- vehicles loading capacity utilization according to mass and cubic volume,

The mathematical model of analyzed problem requires determining characteristics of its components and taking assumptions. The elements of the waste collection system model are: waste collection points (suppliers), sorting plant (central depot), means of transport (vehicles), transport links (graph edges) between system elements.

Optimization task

For a data:

$\boldsymbol{I}$ – set of transport network nodes (collection points), $\boldsymbol{I}=\{0,1,\ldots,i,j,\ldots,I\}$ $i = 0$ – central depot;

Q_i^q – the mass of waste generated in i-th collection point ($i = 1,...,I$);

$\boldsymbol{K}$ – set of vehicles, $\boldsymbol{K}=\{1,\ldots,k,\ldots,K\}$;

q^k – loading capacity of k-th vehicle (k=1,...,K);

p^k – cubic capacity of k-th vehicle (k=1,...,K);

$w(i)$ – container handling time in i-th collecting point, ($i = 1,...,I$);

$d(i,j)$ – length (in km) of shortest path between i-th and j-th collecting point;

$t(i,j)$ – travelling time (in min.) on transport link between i-th and j-th collecting point;

T – maximal daily work time set for driver.

One must find values of matrixes of decision variables *X*

$$X = \lfloor x_{ijk} : x_{ijk} \in \{0,1\} \rfloor \quad i, j \in I, \ k \in K \qquad (2)$$

where $x_{ijk} = 1$ when link (i, j) is attributed to k-th vehicle route.

to minimize a criteria function:

$$f(x) = \sum_{k=1}^{K} \sum_{i=0}^{I} \sum_{j=0}^{I} d(i,j) x_{ijk} \rightarrow \min \qquad (3)$$

Model must take into account constrain as follows:

– all wastes must be collected from collecting points,

– loading and cubic capacity of vehicles can't be exceeded,

$$\forall k \in \boldsymbol{K} \quad \sum_{i=1}^{I} Q_i^q \sum_{j=0}^{I} x_{ijk} \le q_k \wedge$$

$$\forall k \in \boldsymbol{K} \quad \sum_{i=1}^{I} Q_i^p \sum_{j=0}^{I} x_{ijk} \le p_k \qquad (4)$$

– total working time t for each vehicle must not be exceeded,

– each j-th and i-th collection point is attributed only to one route:

$$\forall j \in \boldsymbol{I} \quad \sum_{k=1}^{K} \sum_{i=0}^{I} x_{ijk} = 1 \wedge$$

$$\forall i \in \boldsymbol{I} \quad \sum_{k=1}^{K} \sum_{j=0}^{I} x_{ijk} = 1 \qquad (5)$$

– decision variable x_{ijk} is equal to 1 when node j is serviced in k-th route directly after node i, or 0 in opposite cases:

$$\forall j \in \boldsymbol{I} \quad \forall k \in \boldsymbol{K} \quad \sum_{i=0}^{I} x_{ijk} - \sum_{p=0}^{I} x_{jpk} = 0 \qquad (6)$$

– each route must include central depot $i = 0$:

$$\sum_{k=1}^{K} \sum_{i \in \boldsymbol{I}} \sum_{j \in \boldsymbol{I}} x_{ijk} \le I - 1 \qquad (7)$$

$$\forall k \in \boldsymbol{K} \quad \sum_{j=1}^{I} x_{0jk} \le 1 \quad \wedge \quad \sum_{i=1}^{I} x_{i0k} \le 1 \qquad (8)$$

– the time of route realization is limited:

$$\forall k \in \boldsymbol{K} \quad \sum_{i=0}^{I} \sum_{j=1}^{I} \big(t(i,j) + w(j)\big) x_{ijk} \le T \qquad (9)$$

Criteria function minimizes total length of routes of vehicles collecting wastes.

5. THE EXAMPLE OF USING COMPUTER APPLICATION TO ASSESS WASTE COLLECTION ORGANIZATION IN WARSAW AGGLOMERATION

5.1. GENERAL CHARACTERISTICS OF SOFTWARE FOR MULTI-CRITERIA EVALUATION OF VARIANTS

Supporting investment decision through alternative variants evaluation was done by SuperChoose application. The application was programmed Delphi XE environment and is available for Microsoft Windows users. Figure 5 presents splash screen of SuperChoose application.

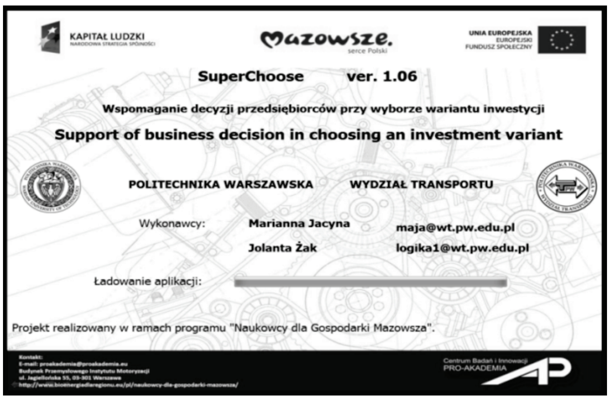

Fig. 5. SuperChoose application splash screen

SuperChoose application consists of three modules; the input module for data entry, computing module containing two methods of multi-criteria decision support, and an output module to save and present results. Data can be entered directly or from Excel worksheets. Application SuperChoose allows applying rank method or MAJA method. It supports decision-makers in performing multi-evaluation and selecting best investment option. The results can be presented as tabular or graphical.

5.2. WASTE COLLECTION ORGANIZATION VARIANTS – ASSUMPTIONS AND RESULTS

For the efficient management of waste in metropolitan area the appropriate organization of waste collection is necessary, so one must:

- plot areas of operation and optimal routes,
- define the functions of central depot,
- determine service time for specific areas,
- constitute sorting plants and select appropriate location,
- find best location for transshipment points.

The important technical aspects are:

- selection of appropriate means of transport for the collection of municipal waste
- selection and proper stowage of the containers for municipal waste collection.

The detailed plan of waste collection was developed on the example of Targowek Warsaw district. The district was divided into areas of operation. Areas have been distinguished on the basis of population density, number of properties to service, and road types. It was assumed that:

1. each area has attributed only one vehicle, service is finished when last drive to central depot (sorting plant) is finished,
2. the mean velocity between points is 15 [km/h],
3. distance to the sorting plant is 10 [km], covered with an average speed of 30 [km/h],
4. stopping and moving in each collecting point consumes additional 40 seconds,
5. garbage containers in the area are filled to the same level,
6. waste collection for 5 variants is done once a week, it is assumed that containers are filled completely,

The study was conducted for five variants of waste collection organization in Targowek district (Fig. 6). For each variant, the following assumptions were made:

1. Finding routes for the selected area without software support, vehicle Eco-Cel Super Medium of capacity of 11 m^3.
2. Finding routes for the selected area with a "Route Optimization" application for existing locations of garbage containers. A vehicle used Eco-Cel Super Medium.
3. Reallocation of garbage containers at a maximum distance of 80 meters from the property, and identification of new routes with computer application. A vehicle used Mercedes Gessink of capacity of 13 m^3.
4. Finding routes for the selected area with a "Route optimization" application for existing locations of garbage containers. A vehicle used Dulevo 5000 Compatto EU4 of capacity of 10 m^3.

Reallocation of garbage containers at a maximum distance of 80 meters from the property, and identification of new routes with computer application. A vehicle used Dulevo 5000 Compatto EU4.

Fig. 6. Analyzed area in Targowek district.
Source: www.targeo.pl

Assumptions for all variants are gathered in table 4.

Table 5 summarizes the evaluation criteria for five variants derived from the "Route optimization" application and additional calculations.

Applying SuperChoose application gave assessment of the options. Figure 7 and 8 show the results of a multi-criteria evaluation through rank method and Figure 9 and 10 through MAJA method.

Table 4. General assumptions for all variants

Pos.	Assumption	Value
1	Garbage containers capacity	1,1 m^3
2	Weight of garbage in container	150 kg
3	Daily amount of waste generated per capita in analyzed area	0,35 kg ([1])
4	Vehicles in variant 1st and 2nd: three-axle vehicle Eko-Cel Super Medium of loading capacity of:	22 m^3 (degree of waste compaction 1:4)
5	Vehicles in variant 3rd: three-axle vehicle of loading capacity of:	26 m^3 (degree of waste compaction 1:4)
6	Number of vehicles serving the area	1
7	Mean velocity between stopping point in the area	15 km/h
8	Average time of vehicle moving and stopping	t_{rz} = 40s.
9	Distance to the sorting plant (both directions)	10 km
10	Mean velocity on a route to the sorting plant	30 km/h
11	Garbage collection for three variants is done once a week, the complete filling of containers is assumed	Once a week
12	Number of containers	243

Source: own materials.

Table 5. Evaluation criteria for all variants

No.	Characteristics	Value				
		Variant 1	Variant 2	Variant 3	Variant 4	Variant 5
1	Total serving time	7,43	6,58	6,32	6,32	6,32
2	Costs of transport	1245,7	1114,2	1035,6	985,6	995,6
3	Unit cost of transport (per container)	5,1	4,6	4,3	4,0	4,1
4	Total distance travelled	48,3	45,4	45,4	51,8	48,9
5	Average loading capacity utilization [%]	72	79	80	82	84
6	Average cubic capacity utilization [%]	68	75	78	84	82
7	Number of vehicles	4	4	3	4	4

Source: own materials.

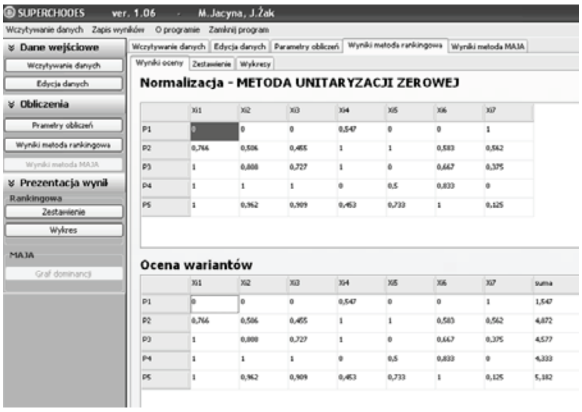

Fig. 7. Results for rank method
Source: SuperChoose application.

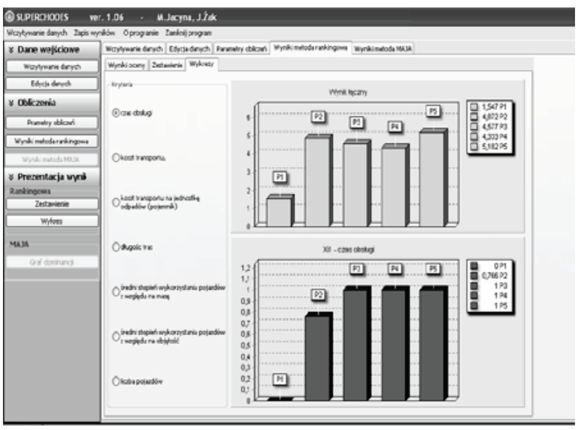

Fig. 8. Charts for rank method
Source: SuperChoose application.

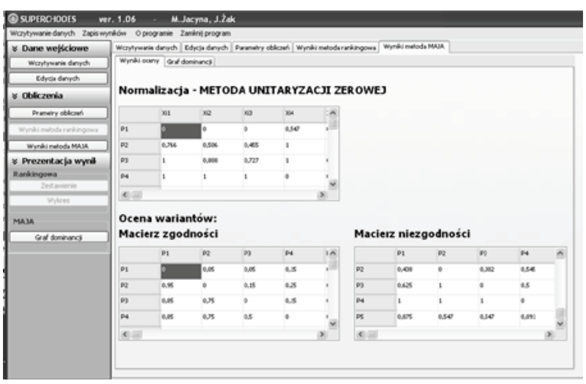

Fig. 9. Results for MAJA method
Source: SuperChoose application.

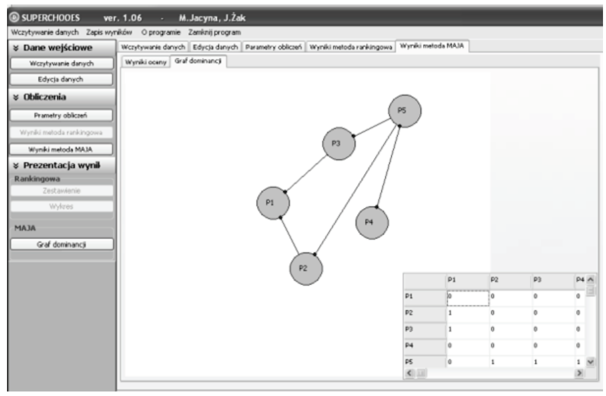

Fig. 10. Charts for MAJA method
Source: SuperChoose application.

6. CONCLUSIONS

SuperChoose application is a useful tool for decision-makers for the analysis and evaluation of investment projects. This application can be:

- A useful tool in analyzing complex projects. The best alternative solution can be found quickly and with a small effort to fulfill expectations of all participants in the decision-making process,
- A helpful tool in complex decisions when a lot of different criteria must be taken into account to find best investment option.

Proper organization of the reverse logistics is a complex multi-faceted decision-making problem. Taken decisions influence the quality of life, economic efficiency of companies, and natural environment. Multi-criteria decision support methods used for the evaluation and ranking of alternatives, can assist the process, and allow finding conditions in which the final – best decision must be done.

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Marianna Jacyna
Warsaw University of Technology, Poland
maja@it.pw.edu.pl

Jolanta Żak
Warsaw University of Technology, Poland
maja@it.pw.edu.pl