APPLICATION OF MCDM/A METHODS TO RANKING DIFFERENT VARIANTS OF THE DISTRIBUTION SYSTEM

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ABSTRACT

The paper presents the methodology of evaluating different variants - development scenarios of the distribution system of goods (dsg). The variants are designed heuristically with the assistance of computer – based object oriented simulation method. Each variant represents an alternative version of dsg, generated through a certain redesign of the existing distribution system. The variants of the dsg are characterized by different measures (characteristics) obtained through the simulation of the operations of each variant. Thus, their evaluation and selection of the most desirable solution is required. In the evaluation process of 5 variants of the distribution system the interests of different stakeholders (owners/ top managers, customers, suppliers, employees and local communities) are taken into account. Economical, social, technical and environmental aspects are considered. A consistent family of criteria is defined to evaluate all the variants – different development scenarios of the dsg. The evaluation of the variants is formulated as a multiple criteria ranking problem, thus all the considered redesign scenarios are ranked from the best to the worst. The methodology of Multiple Criteria Decision Making / Aiding (MCDM/A) is applied. The authors review and analyze a spectrum of MCDM/A ranking methods, including: Electre, AHP, Promethee, UTA and finally select the most appropriate MCDM/A methods that fit best the specific character of the distribution systems' evaluation process. They run computational experiments and present their results. The authors compare the results generated by two MCDM/A methods, i.e. Electre III/IV and Promethee I and draw final conclusions regarding their suitability for the analyzed decision problem.

Keywords: redesign of the distribution system, evaluation of variants, multiple criteria decision making/aiding

INTRODUCTION

Distribution is defined [Czubala, 1996] as the activity based on the flow of products from points of origin to points of destination. The distribution is concentrated on planning, implementing and controlling the physical flows of products [Kotler, 1999]. J. Tarkowski et al. [Tarkowski et al., 1995] describes the distribution as the physical flow of products that involves 6 major processes/ activities: warehousing, goods loading and unloading, transporting, packing and managing. Slightly different components of the distribution process are distinguished by Ross [Ross, 1996], including: warehousing, transportation, finished goods handling and control, customer order administration, site/ location analysis, product packaging, shipping and return goods management. Taking into account many definitions of the distribution the authors consider the distribution system of goods (dsg) as a set of such elements as: logistic infrastructure, human resources, transportation fleet, business processes and organizational rules that provide coordination and control over the above mentioned components. Those components should match together to assure the efficiency and effectiveness of the whole distribution system and a smooth, well adjusted and coordinated flow of materials (products), information and cash. That is why the design and redesign of the dsg is a very complex task (McKinnon 1989; Ross 1996). In the existing dsg its redesign involves the following changes: location of warehouses, reassignment of tasks and redistribution of inventory between warehouses, reassignment of roles and responsibilities among supply chain points, changes in the organization of transportation, fleet replacement, labor force sizing and redistribution, etc.

The redesign of a distribution system may be carried out either in a heuristic manner (Coyle et al. 1996) or in a more rigid conceptual form, based on a mathematical formulation of the redesign process (Hillier, Lieberman 1990). In the first case different development scenarios of the distribution system are designed intuitively, based on the expert knowledge supported by selected quantitative tools e.g. simulation techniques (Law, Kelton 2000; Jansen et al. 2001). The second approach consists in finding the optimal structure of the system, based on the mathematical programming formulation of the decision problem (Novaes, de Cursi, Graciolli 2000). In the literature several combined approaches are also presented to the redesign of the dsg, such as: optimization and simulation methods, MCDM/A methods and optimization etc. G. Wegryn and A. Siprelle (Wegryn, Siprelle 2001) utilize optimization to define the optimal location of warehouses in the dsg and simulation to assign the flow of goods in the optimal structure of the distribution system. J. Korpela and A. Lehmusvaara (Korpela, Lehmusvaara 1999) construct the hierarchy of potential operators of the network of warehouses using MCDM/A method and then maximize the customer service level using the optimization technique. This paper focuses on a combined approach, in which the redesign scenarios of the dsg are constructed intuitively using an object-oriented simulation method (Law, Kelton 2000) and then evaluated by a set of criteria with an application of a selected MCDM/A method. The authors of this paper present the results of their research focused on selecting the most appropriate ranking method for the multiple criteria evaluation of the redesign scenarios of the real-world dsg.

The paper is composed of 6 sections. The first one presents the introduction to the problem at stake. In the second section the methodology of MCDM/A is presented and selected MCDM/A methods: AHP (Saaty 1980), UTA (Jacquet-Lagreze, Siskos 1982), Electre III (Roy

1985; Vincke 1992) and Promethee I (Brans, Vincke, Mareschal 1986) are characterized. In the next section the decision problem is formulated. The real dsg and its alternative redesign scenarios are described, evaluation criteria and DM's preferences are defined. The analysis and selection of the most suitable MCDA method is presented in the section 4. The results of computational experiments carried out with the application of the selected MCDM/A methods are reported in section 5. Last section presents conclusions and further research directions.

THE METHODOLOGY OF MCDM/A. MAJOR FEATURES OF SELECTED RANKING METHODS

MCDM/A is a field which aims at giving the decision maker (DM) some tools in order to enable him/her to solve a complex decision problem where several points of view must be taken into account. MCDM/A concentrates on suggesting “compromise solutions”, taking into consideration the trade-offs between criteria and the DM's preferences (Vincke 1992). The most important roles in the decision making process, based on multiple criteria analysis, play the DM, stakeholders and analyst. The DM is a person (or a group of people), who has a great impact on the decision making process. He/she expresses preferences, evaluates the situation, considers different solutions and approves final results. The stakeholders are all parties involved in the considered decision situation and interested in finding a rational solution for the problem considered. Usually they represent different, sometimes contradictory interests. Their opinions should be taken into account by the DM. An analyst is an expert involved in every stage of the decision process. He/she recognizes the decision problematic, constructs the decision model of the situation, controls the data, explains consequences of certain decisions and selects the appropriate decision making/ aiding tools.

Usually, multiple criteria oriented decision making processes are supported by various computer – based decision tools and methods, generically called MCDM/A methods. Those methods assist DMs in solving, so called: multiple criteria decision problems. Those problems are the situations in which having defined a set of actions (decisions, alternatives) A and a consistent family of criteria F the DM tends to: define a subset of actions (decisions, alternatives) being the best on F (choice problematic), divide the set of actions (decisions, alternatives) into subsets according to certain norms (sorting problematic), rank the set of actions (decisions, alternatives) from the best to the worst (ranking problematic). The classification of MCDM/A methods corresponds to the above classification of multiple criteria decision problems. Thus, one can distinguish MCDM/A:
- choice (optimization) methods,
- sorting methods,
- ranking methods.

Many specialists in the field of multiple criteria decision making/ aiding suggest also the division of MCDM/A methods based on their approach to aggregating global preferences of the DM (Guitouni, Martel 1998), distinguishing two major streams of methods i.e.: the American school based on multiatribute utility theory and the European school based on the outranking relation. Well-known representatives of those streams are: AHP (Saaty 1980), SMART (Edwards 1977), UTA (Jacquet-Lagreze, Siskos 1982) methods, and Electre (Roy

1985; Vincke 1992), Oreste (Roubens 1982), Promethee (Brans, Vincke, Mareschal 1986) methods, respectively. Several methods bridging two schools, including MAPPAC (Matarazzo 1991), are also reported in the literature. In this paper 4 MCDM/A methods including: AHP, UTA, Electre III and Promethee I are considered.

The AHP method (Saaty 1980) carries out pairwise comparison judgments between criteria, and between alternatives with regard to each criterion, quantified on the standard "one – to – nine" measurement scale: 1 – equally preferred; 3 – weakly preferred; 5 – strongly preferred; 7 – very strongly preferred; 9 – absolutely preferred. The intermediate judgments like: 2, 4, 6, 8 can be also used. In the UTA method (Jacquet-Lagreze, Siskos 1982) the DM formulates the reference ranking of selected alternatives. The indifference and preference relations between alternatives are utilized. The model of DM's preferences in the Electre III method (Roy 1985, Vincke 1992) is determined by the indifference q_j, preference p_j, and veto v_j thresholds and weights w_j for each criterion. In the Promethee I method (Brans, Vincke, Mareschal 1986) weights for each criterion are defined. The generalized criterion function and associated indifference and preference values for each criterion are selected.

The MCDM/A methods are utilized in many areas, such as environment (Delhaye, Teghem, Kunsch 1991; Salminen, Hokkanen, Lahdelma 1998), business (Halouani, Chabchoub, Martel 2009; Ngai 2003), manufacturing (Anand, Kodali 2008; Hafeez, Zhang, Malak 2002). Several successful applications of MCDM/A methods have been also reported in the field of transportation and distribution. The results of research carried out within those areas with the application of AHP method are presented by T. Saaty (Saaty 1995) and N. Caliskan (Caliskan 2006). An application of UTA method in transportation is presented by E. Jacquet-Lagreze, J. Siskos (Jacquet-Lagreze, Siskos 1982). The utilization of Promethee method for solving the distribution and transportation problems are presented by R. Dulmin, V. Mininno (Dulmin, Mininno 2003) and B. Elevli, A. Demirci (Elevli, Demirci 2004). The application of Electre method in the considered fields is presented by J. Zak (Zak 2002) and J. Borken (Borken 2005). The comparative analysis of Electre III and AHP methods for the redesign of the distribution system of goods is presented by J. Zak et al. (Zak, Wlodarczak, Kicinski 2002). The same authors utilize Electre III, Oreste and Mappac methods to rank redesign scenarios of a certain logistic system (Zak, Wlodarczak, Kicinski 2001).

THE FORMULATION OF THE DECISION PROBLEM

The problem considered in this paper is formulated as a multiobjective ranking problem. The ranked alternatives are different variants – development scenarios of the distribution system of goods (dsg). The analyzed distribution system has operated since 1993. It has distributed and delivered for sales a full range of electrotechnical products with a total number of 38,5 thousand units, which can be divided into 56 groups. Each group is characterized by certain features. The system consists of 24 distribution centers (DCs) uniformly spread all over Poland. The DCs are differentiated by the area to serve, building structure, warehousing capacity, inventory portfolio, crew size, etc. The system can be divided into 5 echelons (figure 1): a suppliers' level (SL), a central level (CL), a regional level (RL), a local level (LL) and a customers' level (CuL), represented by the set of nodes N_N^{SL}, N_N^{CL}, N_N^{RL}, N_N^{LL} and N_N^{CuL}, respectively. The material flow between the starting node n_{NS} on each level and the ending node n_{NE} is represented by the relation $r_{n_{NS}n_{NE}}$.

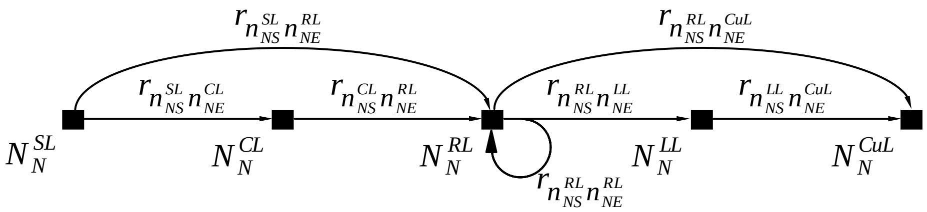

Figure 1. Structure of the analyzed distribution system of goods

A crucial role in the dsg plays transportation, which takes place at every stage of the material flow in the whole network. 12 warehouses on the RL and 1 warehouse on the CL are supplied by the distributors or manufacturers (75 suppliers). Electrotechnical products are transported from CL to RL, from RL to LL and to customers (CuL), and from LL (11 warehouses) to CuL (400 customers). Some products are transported between distribution centers on RL. The final purchasers are individual customers and wholesalers. The deliveries in the distribution system are carried out by road transportation. The transportation services are partially outsourced and partially carried out as in-company activity by a fleet of 55 vehicles including 38 vans and trucks. They operate between different levels of the distribution system.

Based on the comprehensive evaluation of the existing distribution system its strengths and weaknesses have been recognized. To reduce disadvantages of the existing dsg its redesign is proposed. It consists in the introduction of improvements and changes in the dsg. 4 alternative development scenarios of the dsg have been constructed. The variants satisfy to a certain degree the interests of different stakeholders, including: owners/managers of the dsg, final customers, haulers, employees involved in the distribution process. In addition, different aspects of the redesign process, including: economical, technical, organizational and social are considered. Last but not least, the evaluation process involves analysis of different elements of dsg, i.e. logistic infrastructure, transportation fleet, human resources and organizational rules.

In the first scenario slight changes are proposed, such as: the reduction of one distribution center on RL, reorganization of in-company transportation, marginal reduction in the labor force. The last alternative assumes radical transformation of the existing dsg, including relocation of the distribution center on CL, reduction of distribution centers on RL and LL and introduction of 49 retail agents/ shops, complete outsourcing of transportation activities, enlargement of the labor force.

The authors of this paper modeled the variants of dsg in the object-oriented simulation tool ExtendSim. This is a user friendly package which can be used to construct complex models in a graphical form without advanced programming skills [Krahl, 2003]. It is typically used in transportation, logistics, business processes redesign, manufacturing, as well as in healthcare, service and communications industries. This tool is based on continuous and discrete-event methodologies. It provides hierarchy structure of a model, which is very helpful when modelling of a complex system is considered. Its library provides a variety of objects and its structure can be adjusted to specific problems The construction of the model is based on the application of the sequence of objects characterized by certain parameters of their operations. The structure of the simulation model for the existing dsg (variant A_I) is presented in figure 2.

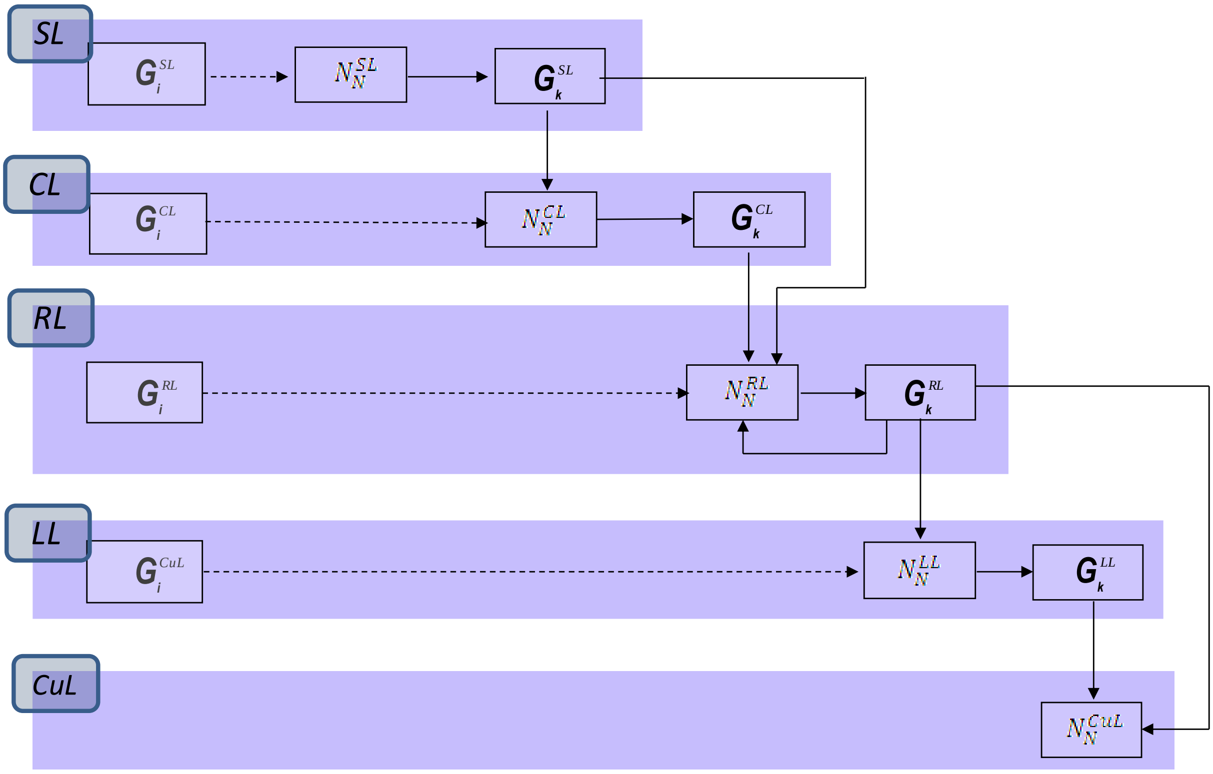

Figure 2. The structure of the simulation model for the existing dsg

The model consists of 5 levels: SL, CL, RL, LL and CuL. Levels SL, CL, RL and LL include the hierarchical objects named $G_i^{SL}, G_i^{CL}, G_i^{RL}, G_i^{LL}$, which are responsible for the generation of information flow based on the ordering structure. These objects are linked with $N_N^{SL}, N_N^{CL}, N_N^{RL}, N_N^{LL}$ hierarchical objects representing suppliers (SL) and distribution centres (CL, RL and LL), which are supplied by the information regarding orders e.g. number of pallets ordered, type of the products ordered, name of the customer, distance from the supplier/ distribution centre to the customer. The physical flow of products is represented by the hierarchical objects denominated by $G_k^{SL}, G_k^{CL}, G_k^{RL}, G_k^{LL}$. The arrows are the connections between suppliers and distribution centers. The CuL level represents the last link in the supply chain - final customers N_N^{CuL}. This generic structure of the simulation model is customized to specific features of variants A_2, A_3, A_4, A_5. In each simulation model representing the operations of variants A_2, A_3, A_4, A_5 respectively, the following structural components are changed: number of the analyzed levels, number and sequence of the objects considered, direction of the information and material flows, specific features and parameters of the analyzed objects.

To demonstrate the practical application of the object-oriented simulation modeling the internal structure of the module G_i for levels SL, CL, RL, LL is presented in figure 3. The authors present the detailed modeling of the information flow in this module.

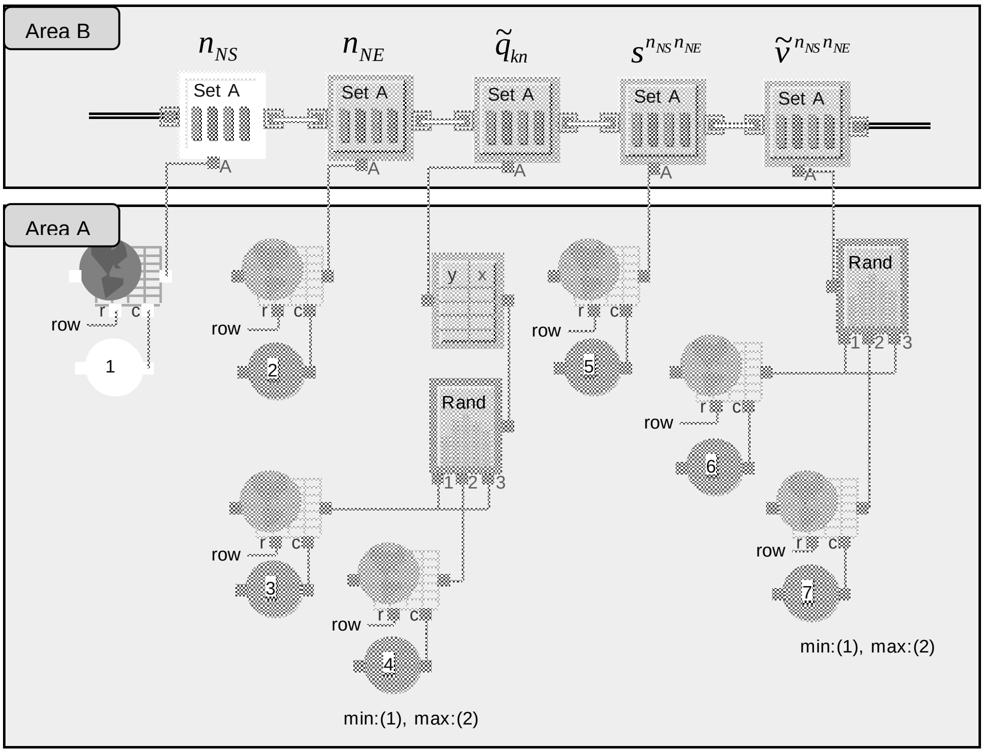

Figure 3. Sequence of objects representing information flow in the simulation model of the existing dsg

One can distinguish two areas A and B, which correspond to the area of information generation and information memorization. In the area B parameters of incoming orders, such as: starting distribution center n_{NS} as a place of incoming order; ending distribution center/ final customer n_{NE}, which placed an order for products; number of ordered products $\tilde{q}_{kn}$ within the assortment k; distance $s^{n_{NS}n_{NE}}$ between n_{NS} and n_{NE}, speed value $\tilde{v}^{n_{NS}n_{NE}}$ between n_{NS} and n_{NE} are modeled. This information is generated by objects presented in the area A and sent to the objects in area B. Objects in the area A are joined with spreadsheets of MsExcel including data collected during the analysis of dsg. Random character of parameters $\tilde{q}_{kn}$ and $\tilde{v}^{n_{NS}n_{NE}}$ is modelled by objects *Rand*, which are responsible for applying distribution parameters.

The variants of dsg are evaluated by a consistent family of criteria [Roy, 1985], which includes different aspects of the considered decision problem and is characterized by non-redundancy and judgmental independence. The set of evaluation criteria is as follows: delivery time [days] - minimized criterion (C_1), distribution costs per day [PLN] - minimized criterion (C_2), utilization of in-company transportation means [%] - maximized criterion (C_3), inventory rotation level [days] - minimized criterion (C_4), utilization of human resources [%] - maximized criterion (C_5), difference between the levels of investments and divestments [PLN] - minimized criterion (C_6), level of order fulfillment [%] - maximized criterion (C_7).

The evaluations of alternatives on all criteria are presented in the matrix of evaluations (table 1). As it was previously mentioned the set of criteria is constructed around expectations of different parties involved in the decision process. The most important criteria for the owner/ manager of the dsg are: distribution costs per day (C_2), utilization of in-company transportation means (C_3), inventory rotation level (C_4) and difference between the levels of investments and divestments (C_6). For the final customer the most important criteria are delivery time (C_1) and level of order fulfillment (C_7). The employees evaluate the dsg with the perspective of utilization of human resources (C_5), while the haulers are interested in distribution costs per day (C_2). Looking at the dsg from different perspectives one can distinguish economical, technical, organizational/ social aspects of its operations and assign above mentioned criteria to those aspects. Criteria C_2, C_6 represent economical aspects, C_3 technical aspect, and remaining C_1, C_4, C_5, C_7 organizational/ social aspects. The set of criteria is also constructed with the perspective of different components of the dsg. One of them are transportation means, which are represented by C_3 and C_6. The next component is infrastructure represented by C_6. Human resources, which are the element of the considered aspect of dsg are represented by C_5. The last component of dsg are organizational rules and the criteria reflecting them are as follows: C_1, C_2, C_4, C_7.

Table 1. Matrix of evaluations of variants on criteria

Variants	Criteria and direction of preferences						
	C_1 [days]	C_2 [PLN]	C_3 [%]	C_4 [days]	C_5 [%]	C_6 [PLNx 1000]	C_7 [%]
	min	min	max	min	max	min	max
A_I	4	3500	33	42	2	0	75
A_{II}	2	3000	40	43	5	4855	75
A_{III}	3	2500	60	32	30	-50	74
A_{IV}	4	2200	65	46	35	10475	80
A_V	1	2400	20	20	36	-385	98

One of the important element of the decision problem are DM’s preferences, which should be recognized and interpreted as his/her perception of the decision situation. Definition of the DM’s preferences is very subjective and individual. In the problem presented in this paper the DM compares the criteria and articulates his/her willingness to compromise, which means that good performance on one criterion can counterbalance a poor one on another. The analysis of DM’s way of articulation of preferences reveals that he is willing to compare variants, perceiving some of them as indifferent, less or more preferred with regard to some criteria. It means that the DM’s preference structure is based on indifference, preference and weak preference relations. Referring to this component of the DM’s preferences it is worth noticing that the above mentioned evaluation criteria are pseudo-criteria - they reflect the relation of indifference, preference and weak preference; the indifference and preference threshold are expressed as constant values.

Based on the information presented in table 1 one can easy select an optimal solution for each particular criterion. On the other hand it is hard to decide, which variant is the most desirable overall. Thus the authors of this paper apply the methodology of MCDM/A to select a so called compromise solution for the considered decision problem. They carry out the analysis of selected MCDM/A methods, identify their strengths and weaknesses and show which of them are most suitable to be applied in the analysis of considered decision problem.

SELECTION OF THE MCDM/A METHODS FOR THE ANALYZED DECISION PROBLEM

The comparative analysis of the selected ranking methods: AHP, UTA, Electre III, Promethee I revealed their advantages and disadvantages. The most important aspects of the analysis are presented in table 2.

Table 2. Selected strengths and weaknesses of the analyzed MCDM/A methods

MCDM/A methods	Strengths / Weaknesses
AHP	Strengths
	- hierarchical representation of the considered decision problem, which gives clear, formal structure of the situation; very useful for complex problems (Goodwin, Wright 1998); - precise comparisons between criteria, and between variants, which allows the DM to focus on each component of the decision problem separately; - final ranking of variants, based on the calculation of their utilities informs about the distance between them.
	Weaknesses
	- inconsistencies of the DM judgments based on the restriction of 1 to 9 scale, e.g. if *A* is considered to be as 5 times more important than *B*, and *B* is 5 times more important than *C*, then *A* should be judged to be 25 times more important than *C*, which is not possible (Goodwin, Wright 1998); - consistency index CI is often higher than 0.1 and the improvement of its value is ambiguous – different opinions of researchers (Finan, Hurley 1997; Linares 2009); - if the number of criteria /variants increases and the number of hierarchy levels is higher, the number of judgments from DM is larger, which increases the labor intensity of the decision process and reduces the attractiveness of the method (Olson et al. 1995).
UTA	Strengths
	- construction of reference ranking of alternatives does not consumes a lot of time: incorporates a small number of information, the DM operates on preference and indifference relations during its construction; - final ranking of variants informs about the distance between them.

	Weaknesses
	- reference set of alternatives is useful for a large number of alternatives i.e. at least 10 (Belton, Stewart 2002); - on the other hand for the large number of alternatives the choice of reference set might cause problems for the DM; - if the reference set consists of the variants in which each one dominates the next one, then this adds no useful preference information (Belton, Stewart 2002).
Electre III	Strengths
	- precise and sophisticated modeling of DM's preferences - DM's preferences between variants are expressed separately for each criterion, the value of threshold (indifference q_i, preference p_i, veto v_i) might be constant or proportional to the value of criterion; - the DM's model of preferences includes different thresholds, such as: indifference, preference and veto, which gives a wide spectrum of DM's preference definitions; - weights of the criteria express trade-offs between criteria.
	Weaknesses
	- precise modeling of DM's preferences, which requires a lot of work; - distillation procedures can give unexpected results, e.g. an improvement of an variant's performance can lead to a poorer ranking position of this variant (Belton, Stewart 2002); - addition or removal of variant can alter preferences between remaining alternatives (Wang, Triantaphyllou 2008).
Promethee I	Strengths
	- precise and sophisticated modeling of DM's preferences - DM's preferences between variants are expressed for each criterion, the preference function for each criterion is defined; - weights of the criteria express trade-offs between criteria.
	Weaknesses
	- relative position in the final rank between variants can change by adding or deleting another variant (de Keyser, Peeters 1996); - method can only be used with criteria for which the differences between evaluations of variants are meaningful (de Keyser, Peeters 1996).

Three major aspects should be taken into account while considering the choice of the most suitable MCDA method i.e. comparative analysis of the wide spectrum of the methods (e.g. their axiomatic analysis, practical applicability), recognition of the decision problem (e.g. including nature and type of available information, emergency and timing of the decision) and identification of the DM's preferences (e.g. his expectations regarding final results, articulation of preferences). All those components are interconnected and influence on the final recommendation of selected MCDA method.

The authors carried out the axiomatic analysis of selected MCDM/A methods. Based on this research they presented the most important strengths and weaknesses of those methods. Analysis of practical applicability revealed that those methods are widely used in the field of distribution and transportation, which are the subject of considerations in this paper.

In the considered decision problem time horizon of the decision made (selection of the redesign scenario) is relatively long (about 2 months), which indicates that the methods are appropriate from this point of view. The DM assumes that required improvements of the dsg should be introduced to the system in a stepwise manner. The analysis of data available in the dsg revealed that their nature and type is deterministic and cardinal. The first component is applicable in all considered methods, while the second only in AHP, Electre III and Promethee I methods. The DM expresses preferences a priori, which is assumed in all methods. His expectations with regard to the results are formulated as the hierarchy of alternatives including the best and the worst one. Such a structure, expressed by the final rank of variants, provide all selected MCDM/A methods.

Based on the analysis of the decision problem, DM preferences, strengths and weaknesses of the considered MCDM/ A methods, the authors noticed that the most important disadvantage of the UTA method is its usefulness only for a large number of alternatives. Indeed, it is hard for the DM to create the reference ranking based on 5 alternatives. This limited number of alternatives suggests the elimination of UTA method from further considerations. Thus, the UTA method can not be applied for the multiple criteria ranking of different alternatives of the considered dsg.

Based on the assumptions of AHP method the structuring of the considered problem, including the construction of the objective of the decision problem, the set of criteria, the set of alternatives, is the advantage of the method. One of the most important weaknesses is the poor way of articulation of the DM's preferences i.e. limited to indifference and preference relations. The DM's perceives the scenarios with the highest degree of changes i.e. A_I vs. A_V as incomparable. The AHP method can not provide this relation in the final rank of variants. Moreover, the method for the considered problem is time consuming. The DM must make 91 comparisons, including 21 within criteria pairwise comparisons and 70 within alternatives' pairwise comparisons. Those are arguments against using this method in the considered problem.

The outranking methods i.e. Electre III and Promethee I meet DM's expectations with regard to the identified way of articulation of his preferences (indifference, weak and strong preference and incomparability). They can deal with the small set of variants, relatively small portion of data needed to carry out computational experiments, incomparability relation perceived within the set of variants. The methods seem to be quite similar. It must be pointed out that the selection of individual preference functions for each criterion and parameters assigned to them in the Promethee I method needs a substantial workforce. Moreover, even though the preference function of type V in Promethee I method is equivalent to the model of preferences in Electre III method with constant values of indifference *qi* and preference *pi* thresholds, the preference index (Promethee I method) and concordance index (Electre III method) have different meanings.

Based on those considerations the Electre III method and Promethee I are selected for the computational experiments.

COMPUTATIONAL EXPERIMENTS AND THEIR RESULTS

The computational experiment has been carried out with the application of an original software ELECTRE III/IV and Promethee I methods. In the first phase of the computational procedure of Electre III and Promethee I methods the following information is entered: the set of variants, the family of criteria, the evaluations of variants on all criteria – evaluation matrix (see table 1) and the model of the DM's preferences. The DM defines the weights w_i for each criterion and thresholds of: indifference q_i, and preference p_i, presented in table 3. All variants are pairwise comparable for each criterion, so the DM refuses to use veto thresholds, which is characteristic for ELECTRE III method.

Table 3. Model of the DM's preferences in Electre III and Promethee I methods

Weights, thresholds, generalized criteria*	Criteria C_i						
	C_1	C_2	C_3	C_4	C_5	C_6	C_7
w_i	9	10	5	6	4	7	8
q_i	0.5	200	10	5	6	100	5
p_i	1	500	20	10	20	350	21
ρ(x)	type 5	type 5	type 5	type 5	type 5	type 5	type 5

* Generalized criteria are used only in Promethee I method

The type 5 of the generalized criteria function ρ(x), which is characteristic for Promethee I method, is selected. This type of function (figure 4) represents the closest relation with the Electre III method. Based on the model of the DM's preferences one can conclude that the most important criterion is distribution costs per day – C2, while the least important one is the utilization of human resources – C5.

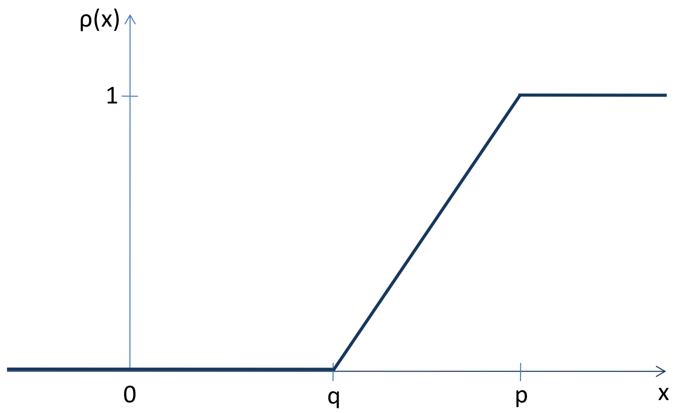

Figure 4. Generalized criteria function in Promethee I method

In the second phase of the computational experiment the outranking relation is constructed. This computational phase consists in the definition and calculation of certain measures and parameters, such as: concordance matrix, (Electre III method) or multicriteria preference index (Promethee I). The concordance matrix (table 4) is based on the value of concordance index, which presents the level of reliability that variant *a* is at least as good as variant *b*. The concordance index is formulated as follows:

$$C(a,b) = \frac{1}{W}\sum_{j=1}^{n} w_j \cdot c_j(a,b)$$

where:

w_j – weight of criterion *j,*

$$W = \sum_{j=1}^{n} w_j$$

$c_j\ (a,b)$ – concordance index for criterion *j*.

Table 4. Concordance matrix in Electre III method

Variants	Variants				
	A_1	A_2	A_3	A_4	A_5
A_1	1	0.61	0.31	0.61	0.1
A_2	0.86	1	0.35	0.61	0.1
A_3	1	0.82	1	0.91	0.4
A_4	0.86	0.67	0.55	1	0.39
A_5	0.97	0.9	0.9	0.9	1

The reliability level that variant A_5 is at least as good as variants A_1, A_2, A_3 and A_4 is very high (close to 1). Very poor results with the lowest value of 0.1 are calculated for the reliability level that variant A_1 is at least as good as variants A_2, A_3, A_4 and A_5.

Multicriteria preference index $\pi(a,b)$ (table 5) is defined for all pairs of variants and calculated on the basis of the type of generalised criteria in Promethee I method. The multicriteria preference index is formulated as follows:

$$\Pi(a,b) = \sum_{j=1}^{n} w_j \rho_j [f_j(a) - f_j(b)]$$

where:

w_j – weight of criterion *j,*

ρ_j - generalized criteria function,

$f_j(a)$, $f_j(b)$ – evaluation of variant *a* and *b* on criterion *j*.

Table 5. Matrix of multicriteria preference index in Promethee I method

Variants	Variants				
	A_1	A_2	A_3	A_4	A_5
A_1	0,0000	0.2653	0.0000	0.1429	0.0306
A_2	0.3878	0,0000	0.1837	0.3265	0.1020
A_3	0.6939	0.6531	0,0000	0.4490	0.1020
A_4	0.3878	0.3878	0.0782	0,0000	0.1020
A_5	0.8980	0.8980	0.6037	0.5816	0,0000

The multicriteria preference index gets the highest value for the variant A_5, which outranks variants A_1 and A_2 (value of index: 0.8980). The lowest value of multicriteria preference index i.e. 0.0000 is calculated for the relation between variant A_1 and A_3.

Next, the descending and ascending distillations (Electre III, figure 5) are calculated and two different complete preorders (P^+, I^+) and (P^-, I^-) in Promethee I method (figure 6), as well. Based on the descending and ascending distillations variants are ranked from the best to the worst. Descending distillation procedure starts from choosing the best variant and placing it at the top of the ranking. From the remaining set of variants, the best one is selected and placed in the second position of the ranking. The procedure stops, when the set of variants is empty. Ascending distillation procedure starts from choosing the worst variant and placing it at the bottom of the ranking. Then the worst variant from the remaining set of variants is selected and placed in the second position of the ranking (from the bottom side). Based on the descending and ascending distillations presented in figure 5 one can see that the best variant is A_V and the worst is A_I. Variants A_{II} and A_{IV} are indifferent.

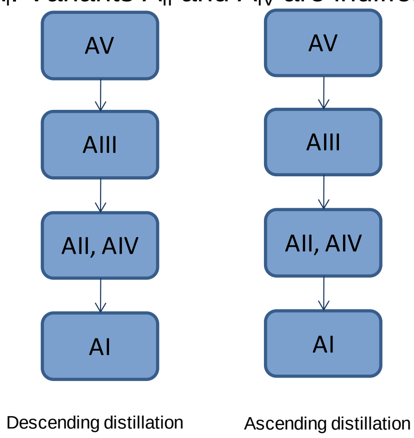

Figure 5. Descending and ascending distillations for ELECTRE III method

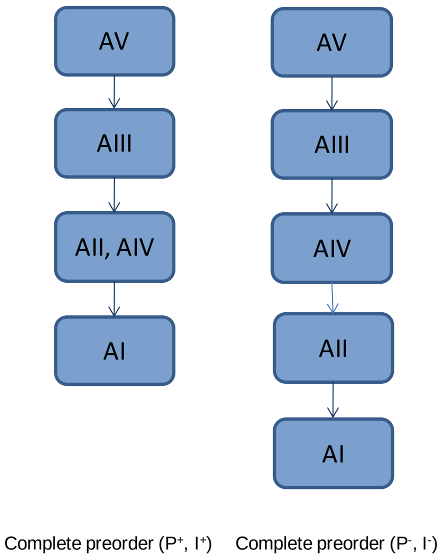

Figure 6. Complete preorders (P^+, I^+) and (P^-, I^-) for Promethee I method

Complete preorders (P^+, I^+) and (P^-, I^-) are calculated on the outgoing and ingoing flows at each variant. The outgoing flow defines the strengths of the variant and the ingoing flow defines the weakness of the variant. The outgoing flow of variant *a* is formulated as:

$$\Phi^+(a) = \sum_{i=1}^{m} \Pi(a,i)$$

and the ingoing flow of variant *a* is formulated as:

$$\Phi^{-}(a) = \sum_{i=1}^{m} \Pi(i, a)$$

To construct the complete preorders (P^+, I^+) and (P^-, I^-) the following relations are computed:

$a\ P^+\ b$ if $\Phi^+(a) > \Phi^+(b)$

$a\ I^+\ b$ if $\Phi^+(a) = \Phi^+(b)$

$a\ P^-\ b$ if $\Phi^-(a) < \Phi^-(b)$

$a\ I^-\ b$ if $\Phi^-(a) = \Phi^-(b)$

Variants A_V and A_I have the same (the best and the worst) position in complete preorders presented in figure 6 as in descending and ascending distillations. Moreover, complete preorder (P^+, I^+) has the same order of variants as the orders in descending and ascending distillations, while in complete preorder (P^-, I^-) their position differs – variant A_{IV} outranks variant A_{II}.

The last phase of the computational phase is focused on the generation of the final ranking of variants. At this point the outranking relation is exploited. The final rankings of variants are presented in figure 7.

Final ranking of variants in Electre III method is based on the joining descending and ascending distillations. In Promethee I the following relations are computed:

$a\ P\ b$ if $a\ P^+\ b$ and $a\ P^-\ b$ or $a\ P^+\ b$ and $a\ I^-$ or $a\ I^+\ b$ and $a\ P^-\ b$

$a\ I\ b$ if $a\ I^+\ b$ and $a\ I^-\ b$

$a\ R\ b$ if not $a\ P\ b$ and not $a\ I\ b$

where:

$a\ R\ b$ – incomparability relation between variants *a* and *b*.

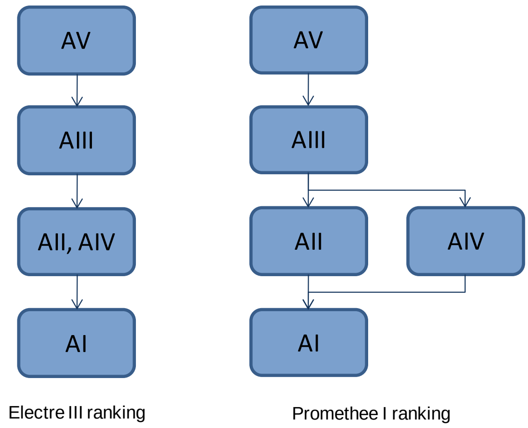

Figure 7. Final ranking of the redesign scenarios of the dsg for ELECTRE III and Promethee I methods

The results of the computational experiments carried out with the application of ELECTRE III and Promethee I methods are similar. They indicate that the best solution is the alternative A_V. This redesign scenario involves the most radical changes in the dsg. Its performances reach the best values on 4 criteria, including: the shortest delivery time, the lowest inventory rotation level, the lowest difference between investments and divestments and the highest level of order fulfillment. The worst alternative in two final rankings is the existing dsg i.e. alternative A_I. The second position in the rankings goes to alternative A_{III}, which is characterized by slight changes. Variants A_{II} and A_{IV} have the same position in the final ranking of Electre III method i.e. they are indifferent. In the Promethee I method they are incomparable. The situation of incomparability between those variants has better understanding from the practical point of view. The smallest number of changes are introduced to the variant A_{II}, while variant A_{IV} assumes a lot of changes. They represent two very different distribution systems, which in practice might have been hard to compare. Differences between the final ranks calculated in Electre III and Promethee I methods are the result of two different methodological approaches in calculating concordance index and multicriteria preference index.

CONCLUSIONS

The decision problem considered in this paper has been formulated as a multiple criteria ranking problem. It consisted in the evaluation and ranking of alternative dsg redesign scenarios and final selection of the best candidate. The variants of the dsg have been constructed heuristically and modelled in the object-oriented simulation tool ExtendSim. The ranking of the dsg redesign scenarios has been carried out with the application of selected MCDM/A methods. The crucial part of the research was focused on the analysis and selection of the most suitable MCDM/A methods for the evaluation of the considered variants of dsg, generating the most reliable and consistent rankings. The selection process was based on the comparative analysis of the MCDM/A methods, the detailed analysis of the decision problem and the collection of DM's preferences. The comparative analysis of selected MCDA methods i.e. AHP, UTA, Electre III and Promethee I revealed their strengths and weaknesses. The definition and characterization of the decision problem and the DM preferences showed the level of suitability of the analyzed methods for the considered problem. Based on the performed analysis the following conclusions can be drawn: the least appropriate is the UTA method. The most important disadvantage is that for the considered decision problem it is hard to define the reference set of alternatives. The UTA method is useful for at least 10 variants, while the set of variants in the analysed dsg equals 5. The AHP method is also not suitable for considered decision situation. One of the weaknesses is that the AHP method doesn't meet the expectations of DM with regard to the preference articulation (indifference, preference and incomparability relations). Moreover, a lot of labor intensity is required in the computational experiments. Thus the method for the considered problem is time consuming. The remaining methods Promethee I and Electre III seem to be similar. As a result of the methods' evaluation process the Electre III and Promethee I methods have been selected. Their main advantage is the precise and sophisticated modeling of DM's preferences. In the Electre III and Promethee I method DM's preferences are expressed separately for each criterion, the DM can express different types of preferences i.e. indifference, weak preference, strong preference, incomparability (only in Electre III method). Both methods can give the final ranks with incomparability relation between variants, which is presented in the problem considered in this paper (final rank in Promethee I).

The final rankings generated by Electre III and Promethee I methods are similar. They show with no doubts that the most desirable variant is A_V, which assumes the most radical changes in the dsg, while the worst one is A_I representing the existing distribution system of goods.

Based on the analysis of the final ranking of alternatives the DM decided to choose the alternative A_V as the most satisfactory solution. This alternative has a lot of advantages represented by the best results obtained for 4 criteria. This variant assumes a lot of changes within the redesign process. They may be made as a step-wise procedure in the long time horizon giving the perspective for better future.

Further research should be based on the construction of methodology for selecting the most suitable MCDM/A for ranking different variants in different systems. This methodology should be verified on the bases of analysis of different distribution systems, responsible for the distribution of such products as: fuel, pharmaceutical products, food etc. The research should include the analysis of a wider group of MCDM/A methods.

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