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MUTLIPLE CRITERIA EVALUATION OF THE DISTRIBUTION SYSTEM OF GOODS

Abstract: This paper presents the most important aspects of multiple criteria evaluation of the distribution system of goods (DSG). The methodology of multiple criteria decision making/aiding is utilized and its 4 phases are described. The first one is based on the recognition of the decision situation. In the second phase the decision problem is formulated. Different scenarios of the system's reorganization are constructed. Then the family of criteria is described and the model of decision maker's preferences is presented. Third phase is based on the selection of the computer-based methods capable of solving the decision problem. In the last phase the computational experiments are carried out. Based on their results, as well as on the sensitivity analysis carried out, the compromise solution is selected. The above presented methodology is verified on the real Polish distribution system of goods.

Keywords: multiple criteria decision making/aiding methodology, MCDM/A methods, distribution system of goods.

1. Introduction

Distribution is defined (Czubala 1996) as an activity based on the physical flow of products from points of origin to points of destination and it is concentrated on planning, implementing and controlling that flow (Kotler 1994). Ross (Ross 1996) distinguishes the following components of the distribution process: 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 coordinated flow of products, information and cash.

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The redesign of the DSG, which is one of the aspects presented in this paper, may involve the following changes (Ross 1996): location of warehouses, reassignment of tasks in warehouses, reassignment of roles and responsibilities among supply chain points, changes in the organization of transportation, labor force sizing, etc.

The above described 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. The second approach consists in finding the optimal structure of the system, based on the mathematical programming formulation of the decision problem. In this paper the first approach to the redesign of the DSG has been applied. Different scenarios of the existing DSG are developed intuitively, with the assistance of computer – based object oriented simulation tool. Those alternatives are characterized by different measures obtained through the simulation of their operations. Thus, their evaluation and selection of the most desirable solution is required.

The authors of this paper present all four phases of the solution procedure of the multiple criteria decision problem. The first one is focused on the recognition of the decision problem. In the second phase the decision problem is formulated. Different scenarios of the system's reorganization are constructed. Then the family of criteria is described and the model of decision maker's preferences is presented. Third phase involves the selection of the computer-based methods capable of solving the decision problem. In the last phase the computational experiments are carried out. Based on their results, including ranking generation and sensitivity analysis, the compromise solution is selected.

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 (Vincke 1992). 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 and defines evaluation criteria, evaluates the solutions and approves final results. The DM is responsible for making final decisions.

The stakeholders are all the 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.

In general, multiple criteria oriented decision making processes are supported by various computer – based decision tools and methods, generically called MCDM/A methods. Those methods assist DM in solving, multiple criteria decision problems.

The latter 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.

In addition to this division, many specialists in the field of multiple criteria decision making/ aiding suggest the classification of MCDM/A methods based on their approach to aggregating the DM's global preferences (Guitouni, Martel 1998), which results in recognizing 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 *et al.* 1986) methods, respectively. Several methods bridging two schools, including MAPPAC (Matarazzo 1991), are also reported in the literature.

All the above mentioned methods are the examples of multiple criteria ranking methods. Four of them i.e. AHP, UTA, Electre III and Promethee I are considered in this paper. They can be used to solve the decision problem presented in this paper, which is formulated as a multiple criteria ranking problem.

The authors of this paper take into account three major aspects while considering the choice of the most suitable MCDM/A method to the considered decision problem i.e. comparative analysis of selected methods i.e. their axiomatic analysis; recognition of the decision problem i.e. identification and formulation of the decision problem, definition of alternatives, their evaluation; and identification of the DM's preferences i.e. articulation of preferences, expectations regarding final results. All those components are interconnected and influence together on the final recommendation of the MCDM/A method selection.

The paper is composed of 6 sections. The first one presents the introduction to the problem at stake. In the second section the DSG is characterized, its strengths and weaknesses are described. The redesign scenarios, evaluation criteria and DM's preferences are presented in the third section. The authors show the analysis and selection of MCDM/A methods in the next section. In section 5 the results of computational experiments carried out with the application of the most suitable MCDM/A methods are presented. The compromise solution is selected. Last section presents conclusions and further research directions. The paper is complemented by the list of references.

2. Real distribution system

The analyzed DSG 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, divided into 56 groups. The DSG consists of 24 distribution centers (DCs) uniformly spread out all over Poland. The DCs are differentiated by the area, building structure, capacity, inventory portfolio.

The DSG is divided into five echelons: a suppliers' level (SL), a central level (CL), a regional level (RL), a local level (LL) and a customers' level (CuL). A crucial role in the DSG plays the transportation process, which takes place between each level of DSG. 1 warehouse on the CL and 12 warehouses on the RL are supplied by the manufacturers and/or distributors (75 suppliers). Electrotechnical products are transported from CL to RL, from RL to LL and customers (CuL), and from LL (11 warehouses) to CuL (400 customers).

Some products are also transported between DCs on RL. The final purchasers are individual customers and wholesalers. The delivery process in the DSG is 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.

Based on the comprehensive evaluation of the existing distribution system its strengths and weaknesses have been recognized. Part of them is presented in Table 1. To reduce disadvantages of the existing DSG four alternative development scenarios have been constructed. They are presented in the next section.

Table 1. *Selected strengths and weaknesses of the DSG*

	Components of the distribution system		
	Logistic infrastructure	**Transportation fleet**	**Business processes and organizational rules**
STRENGTHS	– Central acquisition of the main groups of products	– Modern fleet and handling equipment	– Well organized work in several organizational units – Highly qualified staff
WEAKNESSES	– High level of inventories – Low-utilization of the warehouse space	– Under-utilization of available fleet – Non-homogenous transportation equipment in warehouses on RL	– Over-employment – Inaccurately defined employees functions – Repetition of tasks in different organizational units

3. Formulation of the decision problem

Redesign scenarios

The problem considered in this paper is formulated as a multiple criteria ranking problem. The ranked alternatives are different development scenarios of the distribution system of goods (DSG). The changes in the following areas of the existing DSG, denominated by A_I, have been introduced: organization of the transportation system, number and type of vehicles, equipment of the DSG, location, number and capacities of warehouses, information and material flow. In the first redesign scenario, denominated by A_{II}, 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. Next scenarios i.e. A_{III} and A_{IV} assume more advanced and substantial changes, while the A_V represents radical transformation of A_I, including relocation of DCs on CL, reduction of distribution centers on RL and LL and introduction of 49 shops, complete outsourcing of transportation activities, enlargement of the labor force.

The authors of this paper construct the mathematical model of the DSG and its development scenarios. The alternatives are created heuristically and they are simulated in the object-oriented simulation tool, called ExtendSim (Krahl 2003, Law, Kelton 2000). 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 is very helpful when modeling of a complex system is considered. D. Krahl (Krahl 2003), A. Law, D. Kelton (Law, Kelton 2000) present a detailed description of the ExtendSim simulation tool.

Based on the constructed DSG simulation models the simulation experiments are carried out. More information about the specific features of the simulation models and simulation experiments of the analyzed distribution system of goods are presented in the following papers by H. Sawicka and J. Żak (Sawicka, Żak 2006, 2009a, 2009b)

Family of criteria

During the simulation experiments certain characteristics and measures of the DSG are generated, which are used while defining the evaluation criteria. The authors formulate, a so called, consistent family of criteria (Roy 1985, Vincke 1992), characterized by the following features: it guarantees a comprehensive and complete evaluation of all alternatives, it is composed of measures that are non-redundant and not correlated with each other and it assures fulfillment of overall preferences of the DM.

In the analyzed case 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 performances (Tab. 2).

Table 2. *Matrix of evaluations of alternatives on criteria*

Alternatives	Criteria and direction of preferences						
	C_1	C_2	C_3	C_4	C_5	C_6	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	2500	65	46	35	10475	80
A_V	1	2400	20	20	36	-385	98

The set of criteria is constructed to satisfy expectations and requirements of different parties involved in the DSG. The final decision is made by the DM i.e. owner/ manager of the DSG. The most important criteria for him 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). Looking at the DSG from different perspectives one can distinguish economical, technical, social and organizational aspects of its operations. Criteria C_2, C_6 represent economical aspects, C_3 technical aspect, and remaining criteria C_1, C_4, C_5, C_7 refer to 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 criteria C_3 and C_6. The next component is infrastructure represented by criterion C_6. Human resources, which are the next element of the DSG are represented by criterion C_5. The last component of the DSG are organizational rules that are characterized by such criteria as : C_1, C_2, C_4, C_7.

Decision maker's preferences

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. However, he/she is not prone to any compromise solution

on the criterion C_2. The analyst assesses DM's attitude as a partially compensatory approach (Guitouni, Martel 1998). It means that some kind of compensation is accepted between different criteria e.g. a good performance on one criterion can counterbalance a poor one on another. The degree of compensation needs to be evaluated. Moreover, if two alternatives are compared with regard to one criterion and one of the alternatives is worst than the other, the DM supports the idea that the worse of the two alternatives may be comprehensively considered as good as the better one if its performances on all the other criteria are better.

The analysis of DM's way of articulation of preferences reveals that the preference structure is based on indifference, preference and weak preference relations (Vincke 1992). It means that he/she is willing to compare alternatives, perceiving some of them as indifferent, less or more preferred with regard to some criteria. Referring to this component of the DM's preferences it is worth noticing that the proposed evaluation criteria are pseudo-criteria i.e. it can be taken into account imprecision and uncertainty that may affect performances. This imprecision and uncertainty can be reflected by the above mentioned relation of indifference, preference and weak preference.

The DM states that the most important criterion is the distribution cost per day – C_2, while the least important one is the utilization of human resources – C_5. It is worth mentioning that the DM decides to differentiate the importance of criteria by assigning different weight to each criterion.

The DM's expresses preferences a priori. His/her expectations with regard to the results are formulated as the hierarchy of alternatives including the best and the worst one. Thus, the final ranking of alternatives should have such a structure.

4. Selection of MCDM/A methods

In this paper four multicriteria decision aiding methods are considered i.e. AHP, UTA, Electre III and Promethee I. 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 *et al.* 1986) weights w_j for each criterion are defined. The generalized criterion function and associated indifference q_j and preference p_j values for each criterion are selected.

Based on the analysis of strengths and weaknesses of the considered MCDM/A methods, widely described in Żak, Sawicka (2010), recognition of the decision problem and identification of DM's preferences, the MCDM/A method is selected. Most

of the above described methods are suitable for solving the decision problem considered. However, some of them fit better the problem characteristics than others. The type of the information collected in the DSG is deterministic and the scale of criteria is cardinal. It means that the values of criteria are given as numbers on quantitative (numerical) scale i.e. the gap between two degrees has a clear, quantified meaning in terms of the stated preferences (Roy 2005). The deterministic character of the data is applicable in all considered methods, while the cardinal information only in AHP, Electre III and Promethee I methods. The number of alternatives can be modeled in all considered methods. However, UTA method is useful only for a large number of alternatives i.e. at least 10. It is hard for the DM to create the reference ranking, characteristic for this method, based on 5 alternatives. The AHP 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. On the other hand, 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 one of the most important advantages of AHP method.

One of the most important elements of the appropriate MCDM/A method selection are DM's preferences, which should be recognized and interpreted as his/her perception of the decision situation. His/her partially compensatory approach, as well as a priori expressed preferences are applicable in all considered methods. For most of the analyzed methods only indifference and preference relations are true. The weak preference relation is applied in Electre III and Promethee I methods, only. One of the DM's expectations is the generation of the final ranking of alternatives in the graphical form. This requirement can be satisfied by all the considered methods.

Concluding, the limited number of alternatives defined in the decision problem suggests the elimination of UTA method from further considerations. One of the most important weaknesses of AHP method is the poor way of articulation of the DM's preferences i.e. limited to indifference I and preference P relations, which is an important argument against using this method to solve the considered decision problem.

The remaining outranking methods i.e. Electre III and Promethee I seem to be quite similar. They properly reflect the DM's way of articulating preferences and meet his/her overall expectations, described above. Based on those considerations two methods: Electre III and Promethee I, are selected to be used in computational experiments. The preference function of type V in Promethee I method (Brans *et al.* 1986), which is equivalent to the model of preferences in Electre III method with constant values of indifference qi and preference pi thresholds, is chosen.

5. Computational experiments

Using ELECTRE III and Promethee I methods the following information is entered to run computational experiments: the set of alternatives, the family of criteria 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. The

DM refuses to use veto thresholds. 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 in Electre III method and matrix of mutlicriteria preferences index in Promethee I method. The last phase is focused on the generation of the final ranking of alternatives. In the Electre III method the ranking of alternatives is based on two classification algorithms: descending and ascending distillations. They provide the ranking of variants from the best to the worst. In the descending distillation the best alternative is placed at the top of the ranking, while in the ascending distillation at the bottom.

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_i	type 5	type 5	type 5	type 5	type 5	type 5	type 5

*Generalized criteria are used only in Promethee I method

The final ranking is the intersection of the two distillations. It may include the indifference I, preference P and incomparability R relations between alternatives. In the Promethee I algorithm two different complete preorders (P^+,I^+) and (P^-,I^-) are calculated based on the outgoing and ingoing flows at each alternative. The outgoing flow is also called the positive outranking flow of alternative a. It defines how the alternative a is outranking all the others redesign scenarios. The higher value of outgoing flow the better the alternative a. The ingoing flow, also called the negative outranking flow of alternative a presents how the redesign scenario a is outranked by the others. The lower the value of ingoing flow the better the alternative a. Based on characteristic relations between complete preorders the final ranking of alternatives is generated. It may include the indifference I, preference P and incomparability R relations between alternatives. The final rankings of alternatives are presented in Figure 1.

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.

The comparison of alternative A_{III} with the best alternative in the final ranking revealed that the indifference relation between them is on 2 criteria, preference of AIII over AV is on 1 criterion, while preference of A_V over A_{III} is on 3 criteria and weak preference of A_V over A_{III} is on 1 criterion. Thus, the difference between two analyzed alternatives is substantial. Alternatives 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 alternatives can be better explained by practical aspects. The smallest number of changes is introduced in alternative A_{II}, while alternative A_{IV} is characterized by many, substantial changes. Both alternatives represent two very different distribution systems, and thus it is difficult to compare them. The similar methodological background of Electre III and Promethee I methods results in similar final rankings. Slight differences between the positions of alternatives A_{II} and A_{IV} in rankings are based on different axiomatic of those methods, especially on computing characteristic for those methods indexes i.e. concordance index and multicriteria preference index, respectively.

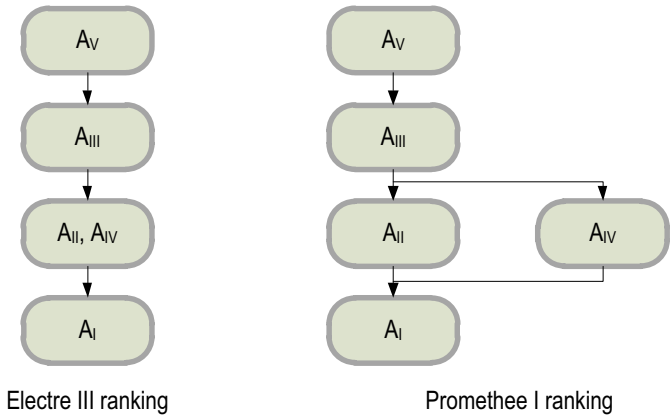

Fig. 1. *Final rankings of the redesign scenarios of the DSG for ELECTRE III and Promethee I methods*

The authors of this paper carried out the sensitivity analysis of the final rankings generated by both methods, to find out how stable the generated results are. In the experiments the models of the DM's preferences have been changed with respect to the weights (importance) of criteria and sensitivity of the DM, represented by the values of respective thresholds. In sequential iterations of the computational experiments both the values of criteria weights and the values of all the thresholds have been increased and decreased by 10%, 25% and 50%. In both methods the increase and decrease of the values of thresholds and weights up to 25% revealed no changes in the final rankings. The changes of results have been observed in final ranking generated by Electre III method when the values of weights and thresholds have been increased and decreased by 50%. The results of 50% changes i.e. increase and decrease for both methods are presented in Figure 2.

The result of experiment based on sensitivity analysis presented in the final graph of Electre III method (Fig. 2), shows that the first, the second and the last positions are occupied by alternatives A_V, A_{III} and A_I, respectively. Comparing this result to the ranking of alternatives presented in Figure 1 (original model of DM's preferences) one can see, that the position of those alternatives is the same in both rankings. In the final ranking for Electre III method presented in Figure 2 alternative A_{IV} outranks alternative A_{II}, while in the ranking presented in Figure 1 alternative A_{IV} and A_{II} are indifferent.

Promethee I method is less sensitive to changes of weights and thresholds than Electre III method (Fig. 2). The changes haven't appeared even with the 50% increase and decrease of criteria weights and threshold values.

The sensitivity analysis carried out proves that the computational results are stable. The slight changes in final ranking of Electre III method shouldn't have an influence on the final decision made by the DM, i.e. selection of the compromise solution. In all rankings the position of the most satisfactory solution is occupied by the same variant i.e. A_V.

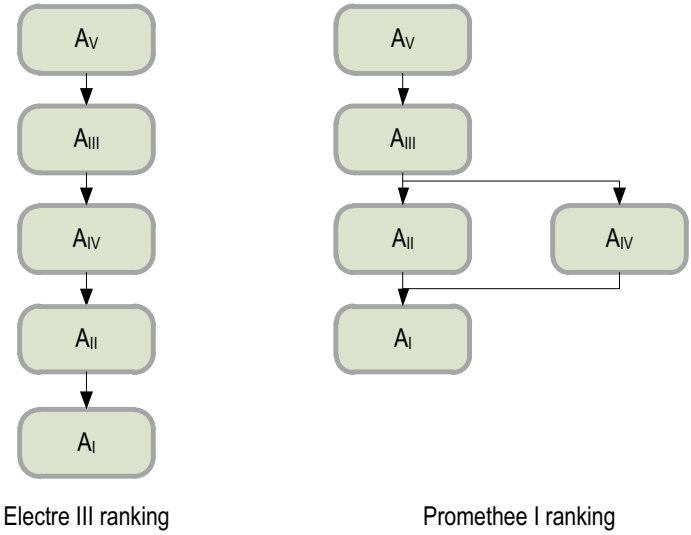

Fig. 2. *Final rankings of the redesign scenarios of the DSG for ELECTRE III and Promethee I methods with 50% increase/decrease of weights and thresholds values*

6. Conclusions

The decision problem considered in this paper has been formulated as a multiple criteria ranking problem. It consisted in evaluation and ranking of alternative DSG redesign scenarios and final selection of the best candidate. According to the multicriteria decision aiding methodology the solution procedure of the decision problem

has involved four phases, including: recognition of the decision situation; formulation of the decision problem i.e. different redesign scenarios, the family of criteria and the model of decision maker's preferences; selection of the computer-based methods capable of solving the decision problem; computational experiments.

The ranking of the DSG redesign scenarios has been generated with the application of selected MCDM/A methods. The selection process of the methods has been based on the methodology proposed by the authors of this paper. This approach concentrates on the analysis of three the most important factors, such as: the comparative analysis of the MCDM/A methods, the detailed analysis of the decision problem and the collection of DM's preferences. As presented in this paper the above mentioned aspects are interrelated. The definition and characterization of the decision problem and the DM's preferences showed the level of suitability of the analyzed methods to the considered problem. The least appropriate one is UTA method, while the most suitable are Electre III and Promethee I methods. Those methods have been used in the phase of computational experiments. Final results show that the compromise solution is alternative A_V, which is characterized by the most radical changes in the existing DSG. This alternative has a lot of advantages represented by the best values of four criteria. Second position in the ranking goes to alternative A_{III}, which is also characterized by advanced and substantial changes in the current DSG. The worst alternative in the ranking is A_I – current distribution system. Alternatives A_{IV} and A_{II} have different positions in the generated rankings.

Based on the analysis of the final rankings, as well as on the sensitivity analysis, the DM decided to choose the alternative A_V as the most satisfactory solution. Even though it requires a lot of changes and the most radical redesign process, it is worth undertaking. The proposed changes can be introduced in a stepwise process, starting from less drastic transformations. Further research should be directed towards the multiple criteria analysis and evaluation of other systems, distributing such products as: fuel, pharmaceuticals, food. The proposed concept of selecting the most suitable MCDM/A method for evaluation and ranking of DSG redesign scenarios should be verified on a larger set of distribution systems. Further research should also include the analysis of a wider spectrum of MCDM/A methods, which can handle non-deterministic data characteristic for simulation methods used to design the alternatives of DSG.

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