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Ranking of distribution system's redesign scenarios using stochastic MCDM/A procedure

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Abstract

The paper presents the original procedure of solving a multiple criteria stochastic ranking problem consisting in the evaluation of different variants of the distribution system. The problem originates from the analysis and construction of the redesign scenarios of the existing distribution system. The authors develop a computational procedure being a combination of a traditional – deterministic multiple criteria ranking method (e.g. Electre III/IV) and a classification algorithm (e.g. Bayes classifier). The proposed method is composed of six steps, including: stochastic data collection, random selection of deterministic numbers using simulation technique, solving a multiple criteria ranking problem with an application of a deterministic multiple criteria decision aiding/making (MCDM/A) method, the classification of deterministic relations between redesign scenarios (variants) to predefined classes using classification algorithm, the construction of a final ranking of redesign scenarios with an application of a spreadsheet, the recommendation of the compromise solution based on stochastic final ranking of redesign scenarios. The proposed approach is verified on the real-world analysis of the distribution system of goods which operates at the Polish electro-technical market. The results of computational experiments, including: ranking generation, classification and sensitivity analysis are demonstrated. The analysts' final recommendation of the compromise solution selection is presented. It is based on a comprehensive analysis of the current state of the system, the perspectives of its development, decision maker's preferences, results of the computational experiments and sensitivity analysis.

Keywords: Multiple criteria stochastic ranking problem, redesign of the real-world distribution system

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1. Introduction

Many definitions of the distribution are presented in the literature, such as e.g.:

- an activity concentrated on planning, implementing and controlling the physical flow of products (Kotler, 1994);
- a process composed of 6 major activities: warehousing, goods loading and unloading, transporting, packing and managing (Tarkowski et al., 1995);
- a process composed of the following activities: warehousing, transportation, finished goods handling and control, customer order administration, site/ location analysis, product packaging, shipping and return goods management (Ross, 1996).

M. Christopher (1986) emphasizes the role of the complex management of the distribution, which is based on the system's approach, e.g. products and information flow should be matched together to ensure the effectiveness of the distribution considered as a system. The authors' of this paper define distribution system of goods (dsg) a set of such elements as (Zak, Sawicka, 2010): logistic infrastructure, human resources, transportation fleet, business processes and organizational rules that provide coordination and control over the above mentioned components.

Since the dsg-s are very complex operational systems influenced by many dynamically changing phenomena they require a multi-dimensional evaluation of their operations (Zak, Sawicka, 2010). One of those dimensions are the interests of different stakeholders (owners/ top managers, customers, suppliers and employees), who benefit from the functioning of the dsg. In some cases the interests of different groups of stakeholders may have contradictory character. Thus, it is necessary to search for compromise solutions that would satisfy them. In addition, the dsg-s have direct or indirect impact on different spheres and are influenced by various environments. That is why in their evaluation different aspects, including: economical, technical social, organizational and environmental should be taken into account. Those aspects constitute the second dimension of the evaluation.

Finally, the dsg is composed of above mentioned diversified components, which are characterized by different measures and characteristics. Logistics infrastructure and transportation fleet are characterized by a set of technical and operational parameters, such as: capacity, age, technical condition. Human resources can be described by such measures as: skills and qualifications, quality of work, experience. Organizational rules and business processes can be measured by the set of performance parameters, such as: assets utilization, business profitability, market share.

Based on the above mentioned considerations it has become transparent that evaluation of the dsg has a multiple criteria character. Different authors propose various parameters and characteristics to evaluate the dsg. Those include (Coyle et al.,1996; Ross, 1996): delivery time, utilization of various resources, order fulfillment reliability and completeness, distribution costs etc. The authors of this paper propose a set of 7 criteria, which are described in the second section of the paper.

Due to the above mentioned multiple criteria character of the dsg evaluation the natural tendency is the application of MCDM/A methodology, which gives the decision maker (DM) some tools in order to enable him/her to solve a complex decision problem in which several points of view must be taken into account (Roy, 1985; Vincke, 1992).

The DM may face different categories of the above mentioned multiple criteria decision problem. For that reason different multiple criteria decision aiding methods have been proposed (Guitouni, Martel, 1998; Vincke, 1992) i.e. choice / optimization methods e.g. Genetic Algorithms (Michalewicz, Arabas, 1994), Pareto Simulated Annealing (Czyzak, Jaszkiewicz, 1998); sorting methods e.g. Electre Tri (Vincke, 1992), Utadis (Zopounidis, Doumpos, 1999) and ranking methods e.g. Electre III (Roy, 1985; Vincke, 1992), UTA (Jacquet-Lagreze, Siskos, 1982). Based on the analytical approach to aggregating global preferences of the DM (Guitouni, Martel, 1998; Vincke, 1992), two major streams of methods can be distinguished i.e.: the American school based on multiatribute utility theory e.g. ANP (Saaty, 2005), SMART (Edwards, 1977) and the European school based on the outranking relation e.g. Promethee (Brans, Vincke, Mareschal, 1986), Oreste (Roubens, 1982). One can also

divide MCDM/A methods with regard to the type of the data handled i.e. deterministic methods e.g. Electre I (Roy, 1985; Vincke, 1992) and non-deterministic / stochastic methods e.g. SMAA-III (Tervonen, Figueira, 2008).

In this paper the authors focus on evaluating different variants of a real distribution system. The decision problem is formulated as a stochastic multiple criteria ranking problem. Its complexity caused that the existing stochastic ranking methods couldn't cope with finding the solution. Thus, the authors of this paper propose an original procedure, which combines a deterministic MCDM/A method Electre III and one of the most popular classification procedures i.e. Bayes classifier (Mitchell, 1997).

Electre III (Roy, 1985; Vincke, 1992) is the representative of the outranking methods. Its global model of preferences is based on the indifference *I*, preference *P* and incomparability *R* relations. The computational algorithm of this method is based on three steps (Zak, 2005):

- construction of the matrix of performances and definition of the model of the DM's preferences,
- construction of the outranking relation,
- exploitation of the outranking relation.

Bayes classifier (Mitchell, 1997) can predict class membership probabilities, such as the probability that an unknown target function $f : x(a) \rightarrow C(z)$, featured by the highest conditional a posteriori probability $P(C(z)|x(a))$ belongs to a particular class $C(z)$. This notation can be interpreted as follows: a certain object x described by the vector of description attributes a, has a chance (probability) $P(C(z)|x(a))$ to be assigned to a certain class $C(z)$.

The algorithm of Bayesian classification is composed of 3 phases, such as (Mitchell, 1997):

- the construction of learning model i.e. classifier,
- testing of the learning model,
- classification of the vector of observations to predefined classes.

The paper is composed of five sections. In the first one the definitions of MCDM/A theory and distribution systems are given. In the second section the real world distribution system is described and the considered decision problem is defined. The authors' procedure of solving MCDM/A stochastic ranking problem and its real world application are presented in sections 3 and 4, respectively. The last section contains conclusions and further steps of the research. The paper is supplemented by a list of references.

2. Problem definition

The considered decision problem refers to a real world distribution system that 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 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 is divided into 5 echelons: a suppliers' level (*SL*), a central level (*CL*), a regional level (*RL*), a local level (*LL*) and a customers' level (*CuL*).

The material flow has been generated by 75 suppliers (distributors or manufacturers) who deliver electrotechnical products to 1 warehouse on the *CL* and 12 warehouses on the *RL* . The products are transported from *CL* to *RL* , from *RL* to *LL* , from *RL* to *CuL* , and from *LL* (11 warehouses) to *CuL* (400 customers). Products may also be transported between distribution centers on *RL* . The final purchasers are individual customers and wholesalers. The deliveries in the distribution system have been 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. To reduce disadvantages of the existing dsg its redesign has been proposed i.e. the improvements and changes have been introduced. 4 alternative development scenarios of the dsg have been constructed. The variants have satisfied to a certain degree the interests of different stakeholders, including: owners/managers of the dsg, final customers, carriers, employees involved in the distribution process.

In the first scenario slight changes have been 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 has assumed 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 have designed and modelled the variants of dsg in the object-oriented simulation tool ExtendSim (Krahl, 2003; Law, Kelton, 2000). More information about the specific features of the simulation models and simulation experiments of the analyzed distribution system of goods have been presented in the following publications by Sawicka and Zak [Sawicka, Zak, 2006; Sawicka, Zak, 2009a; Sawicka, Zak, 2009b, Sawicka, 2012). The results of the simulation experiments include the information about the characteristics and measures of the dsg.

The system is evaluated by a consistent family of criteria (Roy, 1985), which includes different aspects of the considered decision problem and is characterized by non-redundancy. The set of evaluation criteria is as follows: delivery time [days] - minimized criterion (C1), distribution costs per day [PLN] - minimized criterion (C2), utilization of in-company transportation means [%] - maximized criterion (C3), inventory rotation level [days] - minimized criterion (C4), utilization of human resources [%] - maximized criterion (C5), difference between the levels of investments and divestments [PLN] - minimized criterion (C6), level of order fulfillment [%] - maximized criterion (C7).

The evaluations of alternatives on all criteria are presented in the matrix of performances (table 1). It is worth noticing that the dominant type of the information is stochastic, including expected values for criteria C1-C6, calculated for 1-α = 0,9. The remaining criterion C7 has a deterministic character and it is expressed as an average value. The criteria are measured on a cardinal scale which means that their values are given as numbers and the gap between two degrees has a clear meaning in terms of preferential differences (Roy, 2005).

Table 1. Matrix of performances

Criteria		Variants				
		W0	WI	WII	WIII	WIV
C1	Expected value	4	3	2	1	1
	Range of variation*	[3,87; 4,13]	[2,76; 3,20]	[1,78; 2,30]	[0,95; 1,25]	[0,95; 1,13]
C2	Expected value	1,1	1,0	1,4	0,8	0,9
	Range of variation	[0,95; 1,17]	[0,87; 1,05]	[1,24; 1,60]	[0,65; 0,87]	[0,72; 1,04]
C3	Expected value	0,52	0,43	0,50	0,80	0,80
	Range of variation	[0,51; 0,53]	[0,41; 0,45]	[0,44; 0,57]	[0,76; 0,85]	[0,77; 0,83]
C4	Expected value	32	30	28	36	37
	Range of variation	[31,33; 32,67]	[29,84; 30,24]	[27,19; 29,49]	[34,96; 37,44]	[36,68; 37,24]
C5	Expected value	50	50	30	15	10
	Range of variation	[48,80; 52,00]	[48,80; 52,00]	[28,09; 31,51]	[12,57; 17,43]	[8,80; 12,00]
C6	Expected value	21,2	18,6	22,7	0	70
	Range of variation	[19,14; 23,34]	[17,95; 19,17]	[22,54; 22,90]	-	[68,37; 71,71]
C7	Average value	0	-1,0	2,7	7,5	5,8

A large number of information enclosed in table 1 and its stochastic character result in a substantial difficulty in evaluating the considered variants. In some cases the ranges of criteria values for different variants overlap

while in others they are separated. In addition some ranges of criteria are wide, while the others are tight. Manual handling of such an amount of information is difficult, thus it is hard to decide, which variant is the most desirable overall.

To rank the variants from the best to the worst and to find the compromise solution, the authors of this paper apply the stochastic MCDM/A procedure.

3. Key steps of the stochastic MCDM/A procedure

The authors of the paper propose a two-stage stochastic MCDM/A computational procedure that allows to solve a real-world multiple criteria stochastic ranking problem and construct the hierarchy of different variants of the distribution system (see figure 1). The algorithm assists the decision maker in selecting the most desirable concept (variant) of the distribution system, which is considered as a compromise solution. The proposed approach is a combination of a deterministic MCDM/A ranking method (e.g. Electre III/IV) and a classification algorithm (e.g. Bayes classifier).

In the first stage of the computational procedure a large set of rankings is generated. Each ranking is obtained using various criteria values from the feasible range. As a result the positions of variants in these rankings are different and mutual relationships between variants (indifference, preference, incomparability) are distinct.

In the second stage a specific classifier from a family of machine learning methods is applied to process the stochastic information resulting from the analysis of all final rankings. Finally, the non-deterministic (stochastic) relationships between variants are obtained which allows for generating a final classification ranking of the distribution system redesign scenarios.

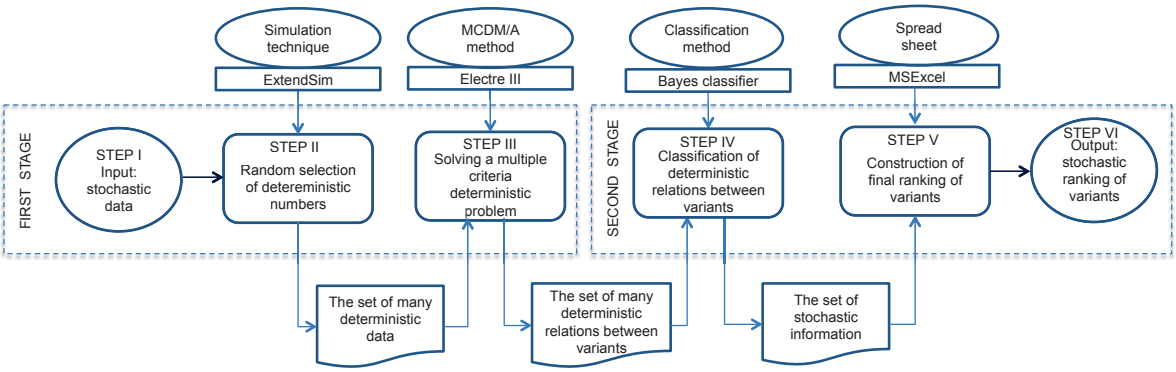


Fig. 1. The paradigm of solving a multiple criteria stochastic decision problem

The proposed approach to solve the stochastic multiple criteria ranking problem can be presented as the composition of the following six steps (Sawicka, 2012; Sawicka, Zak, 2013):

- first stage
  - step I – collection of the stochastic data and definition of DM's model of preferences,
  - step II – random generation within at least 100 iterations (Marinoni, 2005) of deterministic numbers using simulation technique e.g. ExtendSim (Law, Kelton, 2000),
  - step III – solving a multiple criteria deterministic problem for the results of at least 100 simulation iterations, with an application of MCDM/A method e.g. Electre III (Roy, 1985),
- second stage
  - step IV – selection of the training set and vector of observations; classification of deterministic relations between variants to decision attributes (classes) using classification method e.g. Bayes classifier,

- step V – computation of the probability values of an event that a certain relation *I, P, R* between variants occurs; construction of a final ranking of variants constituting the vector of observations with an application of a spread sheet e.g. MS Excel,
- step VI – the selection of the compromise solution based on a stochastic final ranking of variants.

The practical application of the above described computational procedure is presented in the next section.

4. The application of a stochastic MCDM/A procedure

4.1. Step 1 – collection of the stochastic data

In the first step, the stochastic data has been collected and presented as the matrix of performances (table 1). The DM's preferences expressed as deterministic values have also been modeled according to the principles of Electre III method. They are presented in table 2.

Table 2.The model of DM's preferences for the considered decision problem

Criteria	Weights *w*	Thresholds		
		Indifference *q*	Preference *p*	Veto *v*
C1	10	0,60	1,10	2,20
C2	9	0,05	0,10	0,20
C3	5	0,10	0,20	0,30
C4	5	2,00	4,70	8,30
C5	6	6,00	14,00	19,00
C6	4	3,00	5,00	15,00
C7	7	0,50	1,00	3,00

The weights assigned to criteria measure their importance and range from 1 to 10 points. The higher is the value of the weight the more important the criterion is. However, the DM's scale starts from 4 points assigned to criterion C6 and ends at the level of 10 for criterion C1.

While defining the values of thresholds i.e. indifference *q,* preference *p* and veto *v*, the DM has analyzed the expected values and ranges of variation of each criterion. When the distance between thresholds is very short his/her decisions are interpreted as high sensitivity to changes of the values of criteria e.g. C2 ($q = 0,05; p = 0,10; v = 0,20$). When the distance between values of *q* and *p* thresholds is long, then it represents a wide area of DM's hesitation e.g. C5 ($q = 6,00; p = 14,00; v = 19,00$). Finally, when the distance between *q* and *p* thresholds is relatively short and the distance between *p* and *v* thresholds is relatively long, the DM's preferences are interpreted as a narrow area of hesitation and a strong perception of differences between variants e.g. C6 ($q = 3,00; p = 5,00; v = 15,00$).

4.2. Step 2 – random selection of deterministic numbers

In this step, deterministic numbers of each criterion value have been randomly generated. The number of generations (iterations) is 150. More information about these iterations is presented in H. Sawicka doctoral dissertation (Sawicka, 2012) and the authors' paper (Sawicka, Zak, 2013). The result of every iteration is the set composed of deterministic values of criteria for each variant. The example of the set of values for one iteration is presented in table 3.

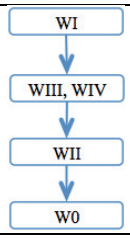
Table 3. Deterministic values of criteria randomly generated in one iteration

Iteration:1					
Criteria	Variants				
	W0	WI	WII	WIII	WIV
C1	3,87	2,87	2,19	1,06	0,99
C2	1,14	0,99	1,29	0,74	0,98
C3	0,53	0,43	0,46	0,82	0,78
C4	31,73	30,03	28,83	36,65	37,18
C5	50,26	51,24	29,80	16,08	8,85
C6	23,05	19,11	22,70	0,00	69,31
C7	0	-1,00	2,70	7,50	5,80

4.3. Step 3 – solving a multiple criteria deterministic problem with an application of MCDM/A method

For each of 150 iterations described in the previous step, the computational experiments with an application of deterministic MCDM/A method Electre III have been carried out. The final ranking matrix of one randomly selected computational experiment and its graphical representation is presented in table 4.

Table 4. Final ranking matrix of variants and its graphical representation for the first iteration

Iteration:1	Variants					Final graph
	W0	WI	WII	WIII	WIV	
W0	I	P-	P-	P-	P-	
WI	P	I	P	P	P	
WII	P	P-	I	P-	P-	
WIII	P	P-	P	I	I	
WIV	P	P-	P	I	I	

This matrix presents the indifference *I,* preference *P* and reciprocal of preference P^- relations between variants e.g. variant WIII is preferred to variant W0 (the relation between variants W0 and WIII is *P*-), variant WIII is indifferent to variant WIV (the relation between variants WIII and WIV is *I*).

The analysis of the total set of data composed of 150 matrices, led the authors of this paper to the conclusion that there are many differences between variants' relations. Thus, they have decided to carry out the classification of these relations, and their allocation to predefined classes. This allocation corresponded to the definition of decision attributes.

4.4. Step 4 – classification of deterministic relations between variants using classification method

Bayes classifier has been applied to solve the classification problem. The following calculations have been carried out (Sawicka, Zak, 2013):

- Initially, 150 matrices have been split into 15 sets with 10 matrices in each of them. For each set the relations between variants represented by the description attributes (i.e. indifference *I*, preference *P*, reciprocal of preference *P*- and incomparability *R* relations) have been recognized and the probabilities of occurrence of particular relationships in the whole set have been calculated. The values of description attributes are in the range [0,1]. Based on them the decision attributes have been constructed. As a result 5 decision classes (attributes) C(z) have been distinguished, including:

C(I) = *I* – indifference relation between variants,
C(P) = *P* – strong preference relation between variants,
C(P-) = *P-* – reciprocal of strong preference relation between variants,
C(Q) = *Q* – weak preference relation between variants,
C(Q-) = *Q-* – reciprocal of weak preference relation between variants.

- The training set *T* has been randomly selected. It has been composed of 10 sets of matrices i.e. around 70% of 15 sets considered in the problem. Based on the information collected in the training set *T* the a priori probabilities *P(C(z))* of an event that the classes *C(z)* occur have been calculated. The conditional a priori probabilities *P(x(a)|C(z))* have been also calculated.
- The testing of a training set *T* has been carried out. The remaining 5 sets of matrices i.e. around 30% of all sets considered in the problem, have been utilized in the computational experiments. The conditional a posteriori probability has been calculated for each pair of variants. Based on the values of the conditional a priori probabilities and the a priori probability of an event that the class *C(z)* occur, the conditional a posteriori probability *P(C(z)|x(a))* that a certain relation between variants occurs has been calculated.
- For each pair of variants from the testing set the classification error β has been calculated. It equals 0,07, which means that the training model has been constructed correctly and Bayes classifier is a good tool for the analyzed problem.
- The vector of observations with a priori unknown decision attributes has been selected. This vector has been composed of 20 relations between pairs of variants (20 relations correspond to the number of relations between variants in one ranking matrix) and has been characterized by the description attributes. Using description attributes 20 decision attributes concerning the relations between variants have been defined. According to the decision attributes 10 pairs of variants have been classified to class *P*, while the remaining 10 pairs to class *P-*. No pairs of variants have been classified to the decision attributes *I, Q* and *Q-*.

4.5. Step 5 – construction of final ranking of variants with an application of spread sheet

In this step the final ranking of variants has been generated. The results have been presented in figure 2.

The compromise solution has been presented at the top of the ranking, while the worst redesign scenario at the bottom. The information concerning probabilities of occurrence of particular relations between variants have been also demonstrated, e.g. the probability of occurrence of relation P between variants WIV and WII is 0,720.

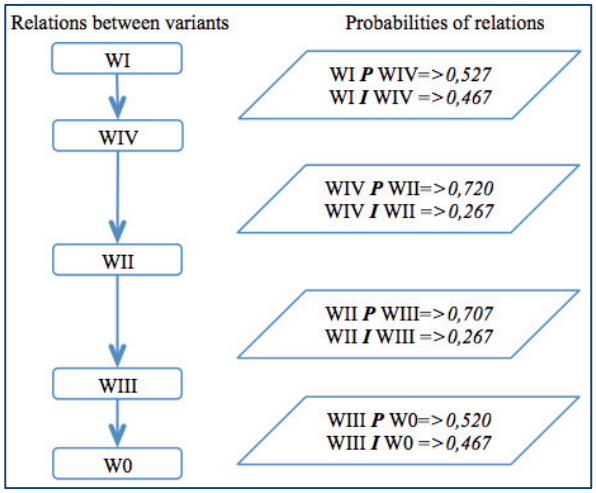


Fig. 2. The final stochastic ranking of variants demonstrating the positions of variants in the graphical form

4.6. Step 6 – the recommendation of the compromise solution based on a stochastic final ranking of variants

In the final step the ranking has been analyzed (Sawicka, Zak, 2013). The leader of the ranking is variant WI. It is featured by slight changes in the existing distribution system of goods. The second position goes to variant WIV, which represents the most radical changes in the dsg. The value of preference relation P (0,527) of variant WI against variant WIV is similar to the value of indifference relation I (0,467) between these variants. In the next position in the final ranking is variant WII. The preference relation between variants WIV and WII is strong and the probability of occurrence of this relation equals 0,720. Variant WII is strongly preferred to variants WIII and W0. The probability supporting strong preference relation between variants WIII and W0 equals 0,520. The indifference relation between these redesign scenarios equals 0,467. Variant W0 has the worst position in the ranking. It represents existing distribution system of goods.

The authors of this paper have compared the results of the computational experiments based on stochastic data analysis to the final ranking of variants obtained from the experiments carried out with an application of Electre III method using deterministic data i.e. expected values. This is a typical approach of aggregating stochastic data into their deterministic equivalent. Moreover, the computational experiments for minimum and maximum ranges of criteria values variations have been also carried out. The results are presented in figure 3.

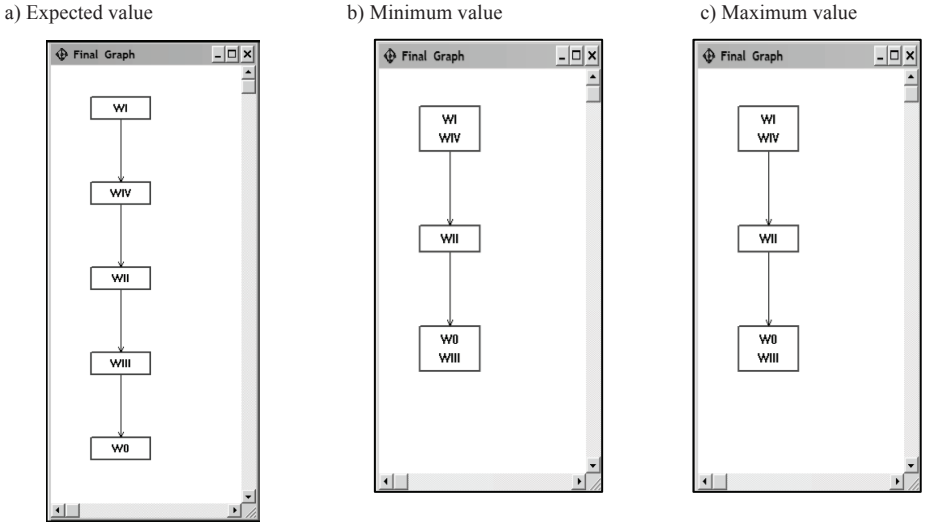


Fig. 3. The final rankings of variants for a) expected, b) minimum and c) maximum values of criteria

All final graphs present variant WI as the compromise solution. However, its position is indifferent to variant WIV in the rankings generated for minimum and maximum values of ranges of criteria values. In the final graph presented in figure 3a, variant WIV has the second position. Variant WII is placed on the subsequent position in all rankings and it is preferred to variants WIII and W0. These rankings are similar to the one presented in figure 2. However, it is not possible to define the distance between variants in the hierarchy based on expected, minimum and maximum values of criteria. The final ranking generated with an application of the procedure proposed by the authors of this paper provides more precise information about the relations between variants than a classical approach based on deterministic values. The analysis based on deterministic data would result in selecting variant WI as preferred to variant WIV. As opposed to that the experiments carried out with the application of stochastic data prove that variants WI and WIV may be considered as indifferent.

5. Conclusions

The decision problem considered in this paper has been formulated as a multiple criteria stochastic ranking problem. It consisted in evaluation and ranking of alternative distribution system redesign scenarios and final selection of the best candidate.

The authors of the paper proposed a two-stage computational procedure that allows to solve a real-world multiple criteria stochastic ranking problem and construct the hierarchy of different variants of the distribution system. The algorithm assists the decision maker in selecting the most desirable concept (variant) of the distribution system, which is considered as a compromise solution. The proposed approach is a combination of a traditional MCDM/A ranking method (e.g. Electre III) and a classification method (e.g. Bayes classifier).

Final results show that the compromise solution is variant WI, which is characterized by the smallest changes in the existing distribution system of goods. Second position in the ranking goes to variant WIV, which is characterized by advanced and substantial changes in the current distribution system. The worst redesign scenario in the ranking is W0 – current distribution system.

Based on the analysis of the final ranking of variants calculated with an application of authors' procedure the following stepwise path of changes is proposed:

- introduction of the evolutionary changes represented by variant WI in the first phase,
- more radical transformation from variant WI to variant WIV in the second phase.

The advantages and disadvantages of the stochastic MCDM/A procedure can be formulated as follows:

- possibility to coping with stochastic data,
- the results of the computational experiments presenting probability of relations occurrence between variants make the anaylsis more complete and final rankings more reliable,
- the procedure has a universal character and can be applied to solve different decision problems,
- the procedure is complex and labor intensive.

Further research should be directed towards:

- the stochastic multiple criteria analysis and evaluation of other systems, distributing such products as: fuel, pharmaceuticals, food;
- adjustment of proposed procedure to uncertain DM's preferences;
- the application and testing of different MCDM/A methods and different classification methods within the procedure.

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