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MULTIPLE CRITERIA DECISION SUPPORT SYSTEM: METHODS, USER'S INTERFACE AND APPLICATIONS

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Abstract. A multiple criteria decision support system has been developed and implemented on the personal computer. Three interactive methods of increasing complexity are realized. The main applications of the system were in the scope of decisions on the best energy development strategy for Lithuania.

Key words: decision support systems, multiple criteria decision making, criteria, Fuzzy preferences.

1. Introduction. People constantly choose and decide though the information about the surrounding world is multicriterial, not precise, limited and uncertain. If the set of decision alternatives is assumed to be predefined, fixed and finite, then the decision problem is to choose the optimal alternative or, maybe, to rank them. What is meant by an optimal decision in the multicriteria situation because it is impossible to simultaneously optimize often conflicting objectives? A typical definition of multicriterial optimality is such: "An optimal decision is the one that maximizes the decision maker's utility".

Usually the optimization approaches require to build a model (objective function) before the optimization starts. In decision support system (DSS) the model evolves progressively and the investigator gets as a result of multicriterial optimization both the optimal decision and additional information about the model. The creation of the model is a step-by-step procedure of constructing the utility function. Decisions of judges are the source of the information.

The problem is to select the best alternative (plan, item, option, candidate, and so on) from the finite set of k alternatives. Any alternative is characterized by c criteria. The criteria may be expressed by some values x^{ij}, $i = \overline{1,k}$, $j = \overline{1,c}$ (e.g., capacity, power, weight). Abstract, verbal criteria (e.g., requirement, feasibility, social effect) are possible, too.

Usually multiple criteria decision support systems are used to solve the problem with the help of judges (experts, voters). The systems are most efficient in the case when the choice of an alternative is crucial (for example, in the work of Hanson, Kidwell and Stevenson (1991) for energy development).

2. Utility function. The decision maker's utility function $w(\cdot)$ is often used as additive (see Keeney and Raiffa, 1976):

$$w(i) = \sum_{j=1}^{c} r^j m^j(x^{ij}), \qquad i = \overline{1,k},$$

where r^j is the weight, and $m^j(\cdot)$ is the individual utility function of the j-th criterion. The values (numerical or verbal) of x^{ij} are initial data; r^j and $m^j(\cdot)$ must be determined in the decision process. When the utility function becomes known, the alternatives may be ranked according to the corresponding values of $w(i)$.

The determination of the utility function in DSS may be divided into two procedures.

1. Normalization of criteria values, i. e., determination of the values of individual utility functions $m^j(\cdot)$, $j = \overline{1,c}$, for all x^{ij}, $i = \overline{1,k}$.For unification the extremal values of $m^j(\cdot)$ for each j may be the same. The Fuzzy method requires to determine the upper bound $u^j(x^{ij})$ and the lower bound $l^j(x^{ij})$ of $m^j(x^{ij})$.

2. Determination of the weights r^j, $j = \overline{1,c}$, of criteria.

3. Requirements to DSS. The presented system is not intended to replace a decision maker but to provide him, by means of computer interface and visual display, with a global view of the problem likely to guide him towards the choice of a decision when constructing the utility function.

The system may be enriched if it has more than one method. So it is preferable to have a "model bank", a set of methods but not a stand-alone algorithm. These methods may be linked by the common use of data. That provides some integration among these methods. The system includes three main components:

- a specialized data base;
- multicriteria decision making methods;
- man–computer interface.

4. The methods. Three methods of increasing complexity are realized in the system:

- paired comparisons of alternatives (see Karpak and Zionts (1989));
- Pareto (see Karpak and Zionts (1989));
- Fuzzy (see Zhang Li Li and Chang Da Young (1992)).

4.1. Paired comparisons of alternatives. The paired comparisons method, introduced by Saaty (1980, 1982), is the simplest one from the user's point of view. The judges must only compare the alternatives two at a time, and determine how important one alternative is relative to the other. Uppuluri (1989) modified the procedure to a simpler case where one needs to determine only whether one alternative is more or less important (or equally important) as the other one.

Assume that a judge says the alternative i to be $a_{ij} > 0$ ($i = \overline{1, k-1}$; $j = \overline{i, k}$) times as important as alternative j. This is equivalent to saying that the alternative j is $1/a_{ij}$ times as important as object i. Thus a judge provides the $k \times k$ reciprocal matrix a_{ij} ($1 \leqslant i, j \leqslant k$). Given these data, there are two procedures to rank the alternatives. Saaty (1977) suggested as the first procedure to rank the alternatives according to the values

$$w(i) = y_i \Big/ \sum_{i=1}^{k} y_i$$

of the i-th alternative, where $(y_1, y_2, \ldots, y_k)$ are the components of the eigenvector, associated with the largest eigenvalue of the reciprocal matrix a_{ij}.

The second is the logarithmic least squares procedure, based on the model:

$$\ln a_{ij} = \ln w(i) - \ln w(j) + \varepsilon_{ij}.$$

Let

$$g_1 = \left(a_{11}\ a_{12}\ \ldots\ a_{1k}\right)^{1/k}$$
$$g_2 = \left(a_{21}\ a_{22}\ \ldots\ a_{2k}\right)^{1/k}$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$g_k = \left(a_{k1}\ a_{k2}\ \ldots\ a_{kk}\right)^{1/k}$$

Then the logarithmic least squares estimates of $w(i)$ are:

$$w(i) = g_i \Big/ \sum_{i=1}^{k} g_i. \tag{1}$$

It may be admitted that the values of criteria are not directly involved in the paired comparisons method. For example, alternatives may be ranked only on the basis of some description of alternatives or other information sources.

4.2. Pareto method. The Pareto method gives a nondominant (Pareto) subset of alternatives to the judge. An alternative is nondominanted if no other alternative is at least as good as it in every respect and better than it is at least one respect. The judge varies the weights of criteria r^j, in the dialog mode and looks for the ranking of alternatives according to the values of the utility function

$$w(i) = \sum_{j=1}^{c} r^j m^j(x^{ij}), \quad \sum_{j=1}^{c} r^j = 1, \; i = 1, k. \tag{2}$$

The values $m(\cdot)$ must be determined by normalization before the variation of weights.

The procedure looks almost like a video game and, in some sense, is similar to the visual interactive method for a continuous set of alternatives developed by Korhonen and Laakso (1986).

4.3. Fuzzy method. The Fuzzy method (Zhang Li Li and Chang Da Young, 1992) is similar to that of Pareto, but the judge has the opportunity to doubt as to his opinion. The reasons for which the Fuzzy approach may be more adequate are:

- uncertainty of a decision maker as to his preferences (hesitation);
- lack of information;
- existence of different opinions (in the group choice).

4.3.1. Triangular fuzzy numbers. The triangular fuzzy numbers and their operation laws will be used. The Fuzzy number $M = (l, m, u)$, $l \leqslant m \leqslant u$, is a triangular, if its membership function is equal to:

$$\mu_M(x) = \begin{cases} \dfrac{x}{m-l} - \dfrac{l}{m-l}, & \text{if } x \in [l, m] \\ \dfrac{x}{m-u} - \dfrac{u}{m-u}, & \text{if } x \in [m, u] \\ 0, & \text{otherwise.} \end{cases}$$

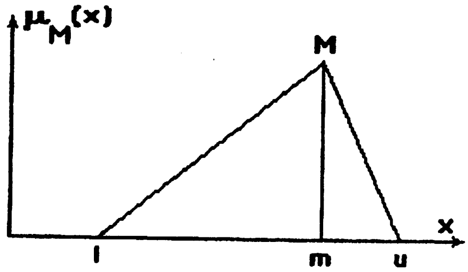

Fig. 1. Membership function of a fuzzy number.

The function $\mu_M(x)$ is illustrated in Fig. 1.

Consider two triangular fuzzy numbers $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$. Then we may introduce for them the operations of addition, multiplication and inversion:

$$M_1 + M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2),$$

$$M_1 \cdot M_2 = (l_1 l_2,\ m_1 m_2,\ u_1 u_2),$$

$$(\lambda, \lambda, \lambda) \cdot (l, m, u) = (\lambda l,\ \lambda m,\ \lambda u), \quad \lambda > 0,\ \lambda \in R,$$

$$M_1^{-1} \simeq \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right).$$

The comparison of fuzzy numbers M_1 and M_2 is based on the degree of possibility of $M_1 \geqslant M_2$:

$$V(M_1 \geqslant M_2) = \sup_{x \geqslant y} \min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right).$$

$$V(M_1 \geqslant M_2) = 1 \ \text{ iff } \ m_1 \geqslant m_2,$$

$$V(M_2 \geqslant M_1) = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}.$$

Fig. 2 illustrates $V(M_2 \geqslant M_1)$ calculation.

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$$V(M \geqslant M_1, M_2, \dots, M_s) = \min_{i=1,s} V(M \geqslant M_i).$$

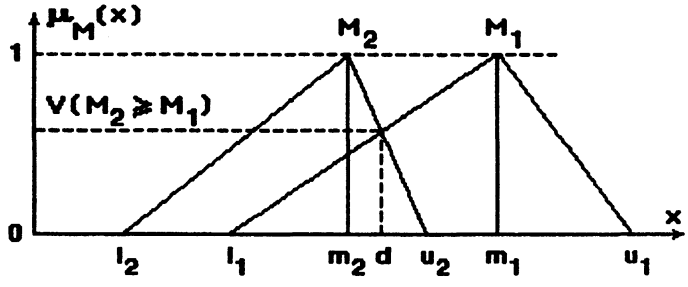

Fig. 2. Illustration of $V(M_2 \geqslant M_1)$ calculation.

4.3.2. Extent analysis and decision. Let us consider a situation having t judges. Every judge (s-th) gives a triangular fuzzy number $M_s^{ij} = (l_s^{ij}, m_s^{ij}, u_s^{ij})$ to the value x^{ij} of criterion j of the alternative i. m_s^{ij} is the main estimate, l_s^{ij} and u_s^{ij} are the lower and the upper bounds. The mean estimate is such: $M_i^j = \frac{1}{t}\sum_{s=1}^{t}(l_s^{ij}, m_s^{ij}, u_s^{ij})$.

Every alternative is characterized by the weighted-sum-type fuzzy synthetic extent similar to that proposed by Zhang Li Li and Chang Da Young (1992):

$$S_i = \sum_{j=1}^{c} M_i^j \cdot r^j \cdot \left[\sum_{j=1}^{c} r^j \cdot \sum_{l=1}^{k} M_l^j\right]^{-1},$$

where r are scalar weights and $\sum_{j=1}^{c} r^j = 1$. A more sophisticated case may be considered when r are fuzzy numbers or depend on the alternative. In short, S_i is the synthetic extent for i-th alternative. Just like in the Pareto method, the judge must give the weights to all criteria.

A scalar measure of the dominance of the alternative i over other ones is as follows:

$$w(i) = \min_{\substack{l=1,2,\dots,k \\ l \neq i}} V(S_i \geqslant S_l). \tag{3}$$

The optimal decision corresponds to the alternative with the maximal $w(\cdot)$.

The optimal alternative may be found taking into account the information obtained from a single judge or from a group of judges. The opinion of a single judge will be represented in the first case, and the second case will show the collaborative opinion.

In fact, the Fuzzy approach requires to get much more information from the judge and is most complicated. The following simplification may be considered: the s-th judge gives only two values of the utility function (l_s^{ij} and u_s^{ij}) to the criterion j of the alternative i; $m_s^{ij} = (u_s^{ij} + l_s^{ij})/2$ may be used.

4.4. Integration of methods. There are two aspects of integration:

- the usage of the same data (weights of criteria r^j, normalized values $m^j(\cdot)$ of criteria) by various methods;
- the normalization of results (1)–(3) (values of utility functions $w(\cdot) \in [0,1]$, $w_{\max} = 1$) for all methods.

5. The structure of the system. The procedure of normalizing criteria values must be used by the judges prior to the usage of Pareto and Fuzzy methods. The flow chart of the system and possibilities for judges' actions are illustrated in Fig. 3.

Each part of the system uses the following information from a specialized data base:

- names of alternatives;
- names and values of criteria;
- names of judges;
- information on the intermediate dialog actions of each judge;
- results obtained by each judge;
- integral results.

The results cover both the optimal solution and the model

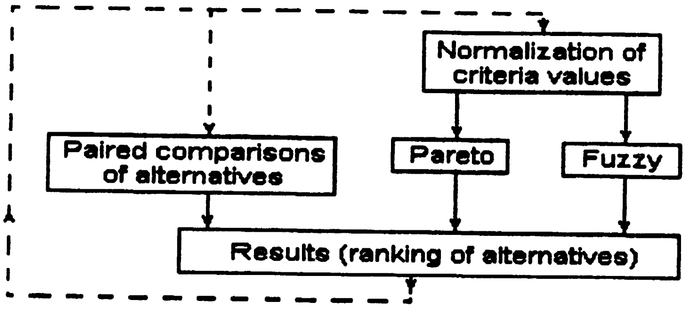

Fig. 3. Flow chart of the system.

of utility functions (weights of criteria, normalized values of criteria).

6. Computer software and applications. The software is devoted to a wide range of specialists (e.g., judges from various applied fields, technologists, physicians). That requires a good man–computer communication. Therefore the user's interface is designed especially friendly, for example, scroll bars are widely used for nonnumerical input of judges' evaluations.

Exploitation of the system is clear and simple due to a completely windowed user's interface based on the Turbo Vision object oriented application framework. The system is available to all modifications of PC AT.

The main applications of the system were in the scope of decisions on the best energy development strategy for Lithuania. The alternatives covered various scenarios of nuclear plant developing, fuel import, electricity export, environmental impact, and so on.

Table 1 of alternatives illustrates the problem of reconstruction of the Pumped Storage Hydro Power Plant (Hydro), Ignalina Nuclear Plant (Nuclear) and installation of the night electric heaters (Heaters).

Table 1. The description of alternatives

Short name of alternative	Number of turbins in Hydro	Number of reactors in Nuclear	Power of Heaters (MW)
H-2, A-2	2	2	–
H-3, A-2	3	2	–
H-4, A-2	4	2	–
H-0, A-1	-	1	–
H-2, A-2, 400	2	2	400
H-0, A-2, 800	–	2	800

Ten criteria (export of energy, fuel saving, degree of nuclear risk and so on) were used by judges to solve the problem. The result was the ranking of alternatives by various methods.

Table 2. The ranking of alternatives: weights and order numbers

Short name of alternative	Methods		
	Paired comparisons	Pareto	Fuzzy
H-2, A-2	1.00 (1)	0.96 (2)	0.94 (4)
H-3, A-2	0.75 (2)	0.96 (3)	0.95 (3)
H-4, A-2	0.38 (6)	0.96 (4)	0.95 (2)
H-0, A-1	0.63 (4)	0.90 (5)	0.78 (6)
H-2, A-2, 400	0.75 (3)	1.00 (1)	1.00 (1)
H-0, A-2, 800	0.63 (5)	0.87 (6)	0.79 (5)

The software for decision support is meant for general purposes. It may be successfully used to solve any other applied problem of similar type.

Conclusions. The main result in creating the system is the suitable choice and adaptation of multicriterial decision support methods. The user has wide possibilities, but on the other hand he is not overpowered by the complexity of his dialog environment.

The experience of using the DSS exposed that human possibilities to concentrate the attention is limited in time. Special requirements to the man–computer interface arose: sophisticated methods are presented in the most understandable form. That is unique way to qualitative and reliable decisions.

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REFERENCES

Hanson, M., S.Kidwell and R.Stevenson (1991). Electric utility least–coast planning. *Journal of the American Planning Association,* **57**(1), 34–45.

Karpak,B., and S.Zionts (Eds., 1989). *Multiple Criteria Decision Making and Risk Analysis Using Microcomputers.* NATO ASI Series, Series F: Computer and Systems Sciences, Vol.56. Springer.

Keeney, R.L., and H.Raiffa (1978). *Decisions with Multiple Objectives.* John Wiley, New York.

Korhonen, P.J., and J.Laakso (1986). A visual interactive method for solving the multiple criteria problem. *European Journal of Operational Research,* **24**, 277–287.

Saaty, T.L. (1977). A scaling method for priorities in hierarchical structures. *J. Math. Psychology,* **15**, 234–281.

Saaty, T.L. (1980). *The Analytic Hierarchy Process.* McGraw–Hill, New York.

Saaty, T.L. (1982). *Decision Making for Leaders.* Lifetime Learning Publications, Belmont, California

Uppuluri, V.R.R. (1989). Prioritization techniques based on stochastic paired comparisons. In Karpak,B., and S.Zionts (Eds.), *Multiple Criteria Decision Making and Risk Analysis Using Microcomputers,* NATO ASI Series, Series F: Computer and Systems Sciences, Vol.56. Spinger, pp. 293–303.

Zhang Li Li, and Chang Da Young (1992). Extent analysis and synthetic decision. In *Support Systems for Decision and Negotiation Processes,* Vol.2. Warsaw. pp. 633–639.

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