MANAGERIAL DECISION-MAKING USING FUZZY PREFERENCE RELATIONS

Hryhoruk P.[1], Khrushch N.[1], Grygoruk S.[1]
[1]Khmelnytskyi National University, Ukraine

Introduction

The quality of economic systems management directly depends on the ability to accurately describe their development and predict the decisions' consequences. Moreover, the complexity of formalization is caused by both the multiplicity and different impact directions of environmental factors, and the presence of feedback loops and time lags in the reaction of the economic system to external influences. As a result, a variety of reasons, like the measurement procedures' imperfection, incomplete data, rapid variability of the environment, lack of reliable information on the activities of competitors, consumer behavior and motivation, changing their preferences, as well as the fact that people in research (experts, consumers) are a main source of information concerning the issues under investigation, the data may be inaccurate, incomplete, possess a high degree of subjectivity in the respondents' assessments of the object studied and therefore be inconsistent. As a result, we often obtain accurate data in the required volume is practically impossible, leading to the use of simplified models of reality. They can actually lead to clear and valid conclusions, then the more detailed and more accurate models. This is reflected in the principle of incompatibility formulated by L. Zadeh [27, p. 201], associated with the human processes of perception and reasoning, which have follows essence: the more complex the system, the less we are able to provide accurate and at the same time having a practical value judgments about it behavior.

Accuracy and practical sense are mutually exclusive features for systems whose complexity exceeds a certain threshold level. In this sense, the quantitative analysis of economic systems does not have significant practical value for real social, economic and other challenges related to the participation of one person or group. As a result, we use generic, inaccurate and subjective understanding about the studied system. Currently, the fuzzy set approach to make managerial decisions is one of the most promising in the formalization of uncertainties. This success is due to the fact that fuzzy mathematics allows you to make decisions based on limited information about the control object. And since in rare cases the manager has complete, reliable, accurate and quantitative information at his disposal, the tools that allow you to make decisions in conditions of its deficit are in demand. In particular, fuzzy set models successfully used in accounting for uncertainty in all areas of management: finance, economics, risk management, insurance, option pricing, investment, marketing, trade, and many others.

Paper [1] considered both of the score-based and fuzzy choice values approaches to decision making, the modifications that account for the model with positive and negative attributes are put forward and discussed for the most common fuzzy negation In paper [4] has studied the construction of financial distress pre-warning fuzzy regression model for investors and risk supervisors. Using fuzzy regression approach to estimate and forecast volatility of option prices has been considered in [18]. Yu et al. [26] have used fuzzy approach to analyze and evaluate the risk levels of credit applicants over a set of pre-defined criteria for support final decision of credit-granting institutions. Walle and Turoff [25] considered information market game. They studied the participants' rankings of the best share in the market based on fuzzy relations and compare the most successful trader to the other traders.

The main results of this analysis is that a substantial number of traders is indeed following the market leader. An efficient and dynamic investment resource allocation mechanism within the framework of a cooperative game with fuzzy coalitions has been introduced in the [3]. Authors shown that this resource investment is influenced by the satisfaction of the players in regard to better performance under a cooperative setup. In the report of Casualty Actuarial Society [23] authored by Shang and Hossen has been studied the applying of fuzzy logic to analyze and assess risks with limited data and knowledge and to estimate the cost of risk mitigation. Early warning bankruptcy models for enterprises using fuzzy logic has been developed by Korol [11].

These models are an "open" application and can be easily used by financial managers as a decisional aid tool in the process of evaluating the financial situation of enterprises and consumers. Lan et al. [12] are developed a bilevel fuzzy principal-agent model for optimal nonlinear taxation problems with asymmetric information, in which the government and the monopolist are the principals, the consumer is their agent. This model may be used with the purpose of maximizing the expected social welfare and the monopolist's expected welfare under the incentive feasible mechanism. A fuzzy attractiveness of market entry model has been developed in [24] to address the decision-making problem of product introduction into alternative markets. Model uses expert opinions regarding four factors: fit of the firm's marketing mix in each market; the fit of its key competitor's marketing mix in each market; environmental conditions in each market; and the strategic importance of each market to the firm.

In papers [15], [16] intuitionistic fuzzy sets introduced by Atanassov [2] have been proposed to build soft decision-making models that can accommodate imprecise information, and two solution concepts about the intuitionistic fuzzy core and the consensus winner for group decision-making have also been developed by other researchers using intuitionistic fuzzy sets. Ideas of using the intuitionistic fuzzy set were evolved in tools of data envelopment analysis [7]. Authors proposed a model for assessment the relative efficiency of a set of congruent decision-making units in finance and credit institution. Modifications of Black–Scholes Option pricing model (OPM) which use a fuzzy approach considered in [8], [13].

Some issues of using the fuzzy sets and fuzzy logic in marketing decision-making have been studied in papers [5] [6], [14], [17], [22]. In particular, Ghaderi and Maihami [6] describes fuzzy expert system for marketing decision model using knowledge-based system. The marketing decision model is used to determine the entrance time of a new product into market. In paper [17] has considered fuzzy analytic hierarchy process (AHP) method as an analytical tool to determine a unique competitive marketing strategy for a small tourism venture. Using a fuzzy logic for multi-agent-based hybrid intelligent systems in support of international marketing planning has studied in [14].

Samadi at al. [22] considered the development of inventory models in a fuzzy environment. They took into account that the quality of services that are offered to customers of a product, the cost parameters in real inventory systems such as price, marketing and service elasticity to demand are imprecise and uncertain in nature. Proposed model uses geometric programming and fuzzy optimization techniques for decision-making.

Taking into account these and many other studies on the application of fuzzy logic and fuzzy sets to solve problems in the area of decision-making, it should be noted that some issues related to the selection of an acceptable alternative under multiple criteria remain open.

The choice of managerial decisions based on fuzzy preference relations

The task of decision-making in the most common formulation is to choose the best alternative from some of the plural. The selection is based on the manager 's preference relationship defined on a set of alternatives. We will be to understand under the preference the estimation of usefulness or quality of the alternative based on the subjective understanding by manager the value and effectiveness of decision. It can be a result of comparing alternatives by the manager in accordance with a generated system of criteria, his intuitive reasoning, the result of the recommendations of the expert group or consultants in decision making. One fairly common approach to estimating the preferences is a paired comparison, having a high degree of objectivity of expert evaluation and independence from criterion's dimension. Thus it is possible to use this approach for both scalar and vector criteria.

The result is a matrix of paired comparisons. An example of this approach is a quantitative representation of the results of comparison in the form of scale Saaty [21] used in the method of analysis of hierarchies. Representation of preference relations in this case has a verbal description. The result may also be in the form of fuzzy preference relation's assessments, in which the degree of preference is given by a numerical value from 0 to 1. Fuzzy preference relations allow, unlike conventional, to take into account the intensity and force of some preference over other options, therefore the using of such relations as a models of expert data representation allow to improve the adequacy of the description of the system of manager's preference and its sensitivity.

Ordering such preference relations take in direction of implementing the search procedures of decisions, so it can be called a priori research of decision-making model. In our opinion, Among the main distinguishing features of marketing decisions can be noted the multiplicity of participants interested in the obtained results, also multi-variant development of the market environment. It leads to the possibility of the emergence of a set of multidirectional criteria for the choice of the best decision. Provided that different participants may have differing optimal in their opinion, behavior strategies, there is a need optimal matching sets of these strategies. This implies the need not organize individual elements of the set of admissible situations, but its subsets Such issues can be solved within a posteriori study of models of decision making, that realizes the reusable searching the set of optimal decision.

Following the ideas described in [9], to make the managerial decision we use such algorithm.

First step, an initial set of alternatives $A^{(0)} = \{A_1, A_2, ..., A_m\}$ is constructed. This set can be described with a certain degree of precision. On the set $A^{(0)}$ we construct the fuzzy subset *A* having membership function $\mu_D(A)$ that describes the extent of the admissibility of each of the alternative decision is given in the original set of $A^{(0)}$. Then, a rational decision can be regarded as a one that will be selected from the subset of alternatives $A^{(D)}$, with the maximum degree of admissibility:

$$A^{(D)} = \left\{A_i \mid A_i \in A, \mu_D(A_i) = \max_j \mu_D(A_i)\right\}, \tag{1}$$

where $i, j = 1..m$.

Next step, constructing a set of partial effectiveness criteria $Q = \{Q_1, Q_2, ..., Q_k\}$ is carried out. Then, for each pair of alternatives (A_i, A_j) we construct membership function $\mu_{ij} = \mu(A_i, A_j)$ of fuzzy preference relationship, which reflected the degree of preference A_i over A_j. For this goal we use formula like (2)

$$\mu_{ij} = \begin{cases} \max\limits_{1 \le s \le k} w_s (Q_{si} - Q_{sj}) \cdot \dfrac{k_{ij}}{k}, & Q_{si} - Q_{sj} \ge 0; \\ 0 & , Q_{si} - Q_{sj} < 0. \end{cases}, \tag{2}$$

where Q_{st} is a value of *s*-th criterion for *t*-th alternative, w_s – weight of *s*-th criterion, k_{ij} – number of values for *i*-th and *j*-th alternatives, for which the condition $Q_{si} - Q_{sj} \ge 0$ is met, $i, j = 1, 2, ..., m$, $s=1,2,...,k$, $t=1,2,...,m$. Other methods for construction the membership functions are describes in [9].

On the third step, a fuzzy strict preference relationship P^S with membership function like (3) is constructed:

$$\mu_{ij}^S = \begin{cases} \mu_{ij} - \mu_{ji}, & \mu_{ij} - \mu_{ji} \ge 0; \\ 0 & , \mu_{ij} - \mu_{ji} < 0. \end{cases} \tag{3}$$

where $i, j = 1, 2, ..., m$.

Then we identify a fuzzy subset of non-dominated alternatives A^{ND} which has a membership function like (4):

$$\mu_i^{ND} = 1 - \max_{j=1,2,...,m} \mu_{ji}^S, \tag{4}$$

and a subset of a strictly non-dominated alternatives A^{UND}, for which the follow condition is met:

$$\mu_i^{ND} = 1, \tag{5}$$

where $i = 1, 2, ..., m$.

In paper [19] this subset of alternatives is called as a Pareto set. It is obvious that the search of decisions should be implemented among a subset of strictly non-dominated alternatives.

Optimal decision is chosen from this subset as any of its alternatives. If subset A^{UND} is empty, we define a subset of *r* - non-dominated alternatives like (6). A value of *r* is chosen according to the (7).

In the general case, the set A^{UND} may be empty, which complicates the argued choice of decision. In our opinion, in this case, is it appropriate to consider a subset of r-non-dominated alternatives:

$$A^{ND}(r) = \{A_i \in A \mid \mu_i^{ND} \geq r\}, \quad (6)$$

which contain alternatives non-dominated at some level of $r < 1$, $i = 1, 2, ..., m$. Decisions should be sought in a subset of *r** - non-dominated alternatives, where *r** is determined according to the rule:

$$r^* = \{\max_{0 \leq r \leq 1} r \mid A_{r^*}^{ND} \neq \varnothing\}. \quad (7)$$

Practical use

Consider practical use presented approach for choice the most appropriate alternatives, provided there are several criteria. Let we have a matrix of normalized values for eight alternatives assessing by the five metric criteria, that presented at the Table 1

Table 1. Normalized values for eight alternatives assessing by the five criteria

Alternatives	Criteria				
	Q_1	Q_2	Q_3	Q_4	Q_5
A_1	0,00	0,00	0,00	0,05	0,00
A_2	0,70	0,19	0,17	0,00	0,40
A_3	0,50	0,22	0,67	0,14	0,60
A_4	0,33	0,25	1,00	1,00	0,20
A_5	0,55	1,00	0,40	0,56	0,70
A_6	0,63	0,95	0,20	0,86	0,60
A_7	0,55	0,30	0,42	0,77	1,00
A_8	1,00	0,48	0,33	0,68	0,70

Analysis of table shows that none of the alternatives have clear preference on others, that predetermines the necessity of additional calculation. Values of membership function of fuzzy preference relationship μ_{ij} are presented at the Table 2, *i*, *j* = 1, 2,..., 8.

Table 2. Values of membership function of fuzzy preference relationship

Alternatives	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
A_1	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00
A_2	0,56	0,00	0,04	0,15	0,03	0,02	0,03	0,00
A_3	0,67	0,40	0,00	0,16	0,05	0,19	0,05	0,07
A_4	1,00	0,60	0,51	0,00	0,24	0,32	0,23	0,27
A_5	1,00	0,65	0,62	0,45	0,00	0,12	0,28	0,31
A_6	0,95	0,69	0,58	0,42	0,12	0,00	0,39	0,19
A_7	1,00	0,62	0,50	0,48	0,24	0,16	0,00	0,18
A_8	1,00	0,68	0,43	0,41	0,27	0,23	0,18	0,00

Using the values of Table 2 we calculate a membership function of fuzzy strict preference relationship μ_{ij}^{S}. Result are shown at the Table 3.

Table 3. Values of membership function of fuzzy strict preference relationship

Alternatives	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
A_1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
A_2	0,55	0,00	0,00	0,00	0,00	0,00	0,00	0,00
A_3	0,67	0,36	0,00	0,00	0,00	0,00	0,00	0,00
A_4	1,00	0,45	0,35	0,00	0,00	0,00	0,00	0,00
A_5	1,00	0,62	0,57	0,21	0,00	0,00	0,04	0,04
A_6	0,95	0,67	0,40	0,10	0,00	0,00	0,23	0,00
A_7	1,00	0,59	0,45	0,25	0,00	0,00	0,00	0,00
A_8	1,00	0,68	0,36	0,14	0,00	0,04	0,00	0,00

Further we construct a membership function of fuzzy set of non-dominated alternatives μ^{ND} (Table 4) and determine according to (7) subset of strictly non-dominated alternatives.

Table 4. Values of membership function of fuzzy set of non-dominated alternatives

Alternatives							
A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
0,00	0,32	0,43	0,75	1,00	0,96	0,77	0,96

Table 4 shows that in this case subset A^{UND} has only single alternative – A_5, which should be choose as a decision. At the same time, it should also be noted high value of membership functions for the sixth and eighth alternatives. If we assume that assessing alternatives have realized by the first four criteria, then values of membership functions $\mu_{ij}, \mu_{ij}^{S}, \mu_{i}^{ND}$ be in the other form (Table s 5-7)

Table 5: Values of membership function of fuzzy preference relationship for four criteria

Alternatives	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
A_1	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00
A_2	0,53	0,00	0,05	0,09	0,04	0,02	0,04	0,00
A_3	0,67	0,38	0,00	0,04	0,07	0,12	0,06	0,08
A_4	1,00	0,75	0,64	0,00	0,30	0,40	0,29	0,34
A_5	1,00	0,61	0,58	0,38	0,00	0,10	0,35	0,26
A_6	0,95	0,64	0,55	0,35	0,15	0,00	0,49	0,23
A_7	0,72	0,58	0,47	0,11	0,16	0,05	0,00	0,05
A_8	1,00	0,68	0,40	0,34	0,23	0,19	0,23	0,00

Table 6. Values of membership function of fuzzy strict preference relationship for four criteria

Alternatives	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
A_1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
A_2	0,51	0,00	0,00	0,00	0,00	0,00	0,00	0,00
A_3	0,67	0,32	0,00	0,00	0,00	0,00	0,00	0,00
A_4	1,00	0,66	0,60	0,00	0,00	0,05	0,18	0,00
A_5	1,00	0,57	0,52	0,08	0,00	0,00	0,19	0,03
A_6	0,95	0,62	0,43	0,00	0,05	0,00	0,44	0,05
A_7	0,72	0,54	0,41	0,00	0,00	0,00	0,00	0,00
A_8	1,00	0,68	0,32	0,00	0,00	0,00	0,18	0,00

Table 7. Values of membership function of fuzzy set of non-dominated alternatives for four criteria

Alternatives							
A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
0,00	0,32	0,40	0,92	0,95	0,95	0,56	0,95

Analysis results presented in the Table 7 shows that subset A^{UND} is empty. Therefore, it is need to define subset of *r** - non-dominated alternatives. In this case we have a result: *r*=0,95; $A^{ND}(0{,}95) = \{A_5, A_6, A_8\}$.

Therefore, it is necessary to use additional information about each alternative for choice the decision, in particular, to include one more criterion for assessing.

Let we consider case, when assessing alternatives is fulfilled by six criteria, among them first four are metric and last two – rank. Initial data are presented in the Table 8.

Table 8. Normalized values for eight alternatives assessing by the six mixed criteria

Alternatives	Criteria					
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6
A_1	0,00	0,00	0,00	0,05	2	3
A_2	0,70	0,19	0,17	0,00	1	5
A_3	0,50	0,22	0,67	0,14	5	7
A_4	0,33	0,25	1,00	1,00	4	1
A_5	0,55	1,00	0,40	0,56	6	8
A_6	0,63	0,95	0,20	0,86	8	6
A_7	0,55	0,30	0,42	0,77	7	2
A_8	1,00	0,48	0,33	0,68	3	4

Values of membership function of fuzzy preference relationship and membership function of fuzzy strict preference relationship are presented in Tables 9, 10.

Table 9. Values of membership function of fuzzy preference relationship for six mixed criteria

Alternatives	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
A_1	0,00	0,17	0,00	0,17	0,00	0,00	0,17	0,00
A_2	0,52	0,00	0,03	0,23	0,03	0,01	0,19	0,17
A_3	0,78	0,58	0,00	0,36	0,04	0,24	0,21	0,39
A_4	0,83	0,67	0,43	0,00	0,20	0,27	0,19	0,39
A_5	1,00	0,74	0,72	0,58	0,00	0,23	0,40	0,51
A_6	0,97	0,76	0,53	0,57	0,27	0,00	0,66	0,49
A_7	0,65	0,55	0,48	0,41	0,27	0,04	0,00	0,20
A_8	1,00	0,62	0,27	0,39	0,15	0,13	0,32	0,00

Table 10. Values of membership function of fuzzy strict preference relationship for six mixed criteria

Alternatives	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
A_1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
A_2	0,34	0,00	0,00	0,00	0,00	0,00	0,00	0,00
A_3	0,78	0,55	0,00	0,00	0,00	0,00	0,00	0,12
A_4	0,67	0,44	0,07	0,00	0,00	0,00	0,00	0,00
A_5	1,00	0,72	0,68	0,38	0,00	0,00	0,13	0,36
A_6	0,97	0,75	0,29	0,30	0,03	0,00	0,62	0,36
A_7	0,48	0,36	0,27	0,21	0,00	0,00	0,00	0,00
A_8	1,00	0,45	0,00	0,00	0,00	0,00	0,12	0,00

The membership function of fuzzy set of non-dominated alternatives in this case is showed in the Table 11.

Table 11. Values of membership function of fuzzy set of non-dominated alternatives for six mixed criteria

Alternatives							
A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
0,00	0,25	0,32	0,62	0,97	1,00	0,38	0,64

Analysis results shows, that in this case alternative A_6, which is strictly non-dominated alternative, is the best.

Presented calculations snows, that use additional criteria for assessing alternatives may cardinally change preference of decision-maker and fundamentally effect on his choice.

Conclusions

At the present time, fuzzy set approach in the field of decision-making is one of the most used. One of the most important issue is the construction of the fuzzy preference relations. We propose the scientific-methodical approach to choosing the most suitable alternative as a managerial decision. It allows to construct a set of Pareto-effectiveness alternatives and to choose the best one as a decision. If we have several alternatives, we should make a choice based on additional reasoning, in particular, using expert assessments, analysis of non-price indices of effectiveness, applying the criterion of minimization of charges and so on.

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