Fuzzy Strategic Decision –Making Models Based on Formalized Strategy Maps

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Abstract— **The paper suggests fuzzy methods to solve multicriteria problems related to resources' optimal use for implementing a strategy based on formalized strategy maps. Fuzzy methods of strategy maps' formalization are described. Two groups of criteria are considered: "strategic" and "economic". The degrees of strategic goals' achievement are the criteria of the former group; and the indicators reflecting the need to bear the costs of resources and their economic efficiency are the criteria of the latter group. The solution is understood as a set of strategic measures, the implementation of which leads to certain "strategic" and "economic" consequences. The fuzzy modifications of the trade-off model, various models of proportional development, and models where multicriteria objective functions are generated through simulation procedures are proposed. The advantages of fuzzy methods are associated with the extensive use of expert assessments in multicriteria models – in particular, in the strategic decision-making models.**

Keywords— strategic decision-making models; strategy formalization; strategy map; fuzzy methods; trade-off model.

1. INTRODUCTION

The process of strategic management in the organization can be divided into three stages in broad strokes: strategic analysis, strategy development and strategy implementation. The transition from the second stage to the third stage is impossible without strategy formalization, the quality of which influences the efficiency of operationalization of the strategy and, ultimately, the success of the strategy implementation.

Strategy formalization is usually carried out on the basis of strategy maps. The idea of strategy maps emerged in the second half of the 1990s in the works of R. Kaplan and D. Norton (within the framework of the Balanced Scorecard concept) [1-4] and other authors [5, 6].

The strategy map elements are strategic goals that are normally distributed over several perspectives, with given hierarchical relations between the perspectives and the goals themselves. Four perspectives were originally identified [7]. Later, the set and the number of perspectives changed for organizations of different types [8-12].

In turn, each goal corresponds to a set of indicators that can also be divided into two or more groups with hierarchical relationships (formative and resultant, for instance). The goal description through a set of indicators allows to eliminate the ambiguity arising due to possible different interpretations of almost any goal formulation [13].

Each indicator is normally assigned its initial and target values. It is believed that the goal is achieved if the goal indicators (all of them, or at least those in the upper group of the hierarchy of indicators) have reached their target values. Strategy formalization requires to determine the influence of the values of the groups of indicators describing each goal on the degree (level) of achieving this goal. The degree of the goal achievement is taken as a number from 0 to 1. The degree of the goal achievement is 0 if the current values of all the resulting indicators are equal to the initial values, or 1 if the goal is achieved. At the same time, if the indicators exceed their target values, the degree of the goal achievement may become less than 1 – even 0 [14]. For convenience, the region of change of each indicator from the initial to the target value can also be transferred in the interval from 0 to 1.

Indicators change their values during the implementation of certain strategic measures (projects). In this regard, strategy formalization involves not only the establishment of links among strategic goals, as well as goals and indicators, but also the impact of measures on indicators (and hence on goals). As such, in the broad sense, the strategy formalization process is understood as the strategy map development process, including the establishment of dependencies among its elements [15]. At the same time, it is not only about the cause and effect relationships, but primarily about the functional relationships, without which neither objective assessment of the economic efficiency of the adopted strategy, nor the solution of the problem of the optimal use of available resources for the strategy implementation (which may even force to adjust or revise the strategy, in general), nor the operational management of the strategy implementation are possible.

The solution of the above problems is impossible without the construction of the relevant strategic decision making models. The authors proposed such models in [16]. The possibility and efficiency of the practical use of such models is limited by the degree of formalization of strategy maps.

The authors earlier proposed methods for finding functional dependencies among the strategy map elements, based on the construction of multicriteria utility functions, to which some specific requirements are presented [15, 17-19]. These methods are applicable with any number of indicators (criteria) and any nature of the relationships among them (indicators may be interdependent). Various problems are normally solved using either one-criterion utility functions or utility functions, the criteria of which are utility independent of each other. Some methods of constructing utility functions with interdependent criteria have been proposed in the work [20], but they are extremely difficult for practical use.

The adaptive algorithm of the expert survey, which allows to define values of the utility functions in the points of the region chosen in a special way, lies at the heart of the proposed methods. Its distinctive feature is the creation of comparative questions to facilitate the experts' task and to obtain more accurate values of utility functions. However, with a large number of variables (criteria), experts find it very difficult to answer even comparative questions. At the same time, the procedure for reconciliation of expert opinions is complicated.

In this regard, the fuzzy methods that can be used to formalize the strategy map were considered [21]. It was shown that the fuzzy analytic hierarchy process [22, 23] and fuzzy inference method [24] could be used to rank the strategy map elements and simplify the finding of functional dependencies among the strategy map elements using previously proposed methods based on constructing the multicriteria utility functions satisfying certain requirements. A method was also proposed for finding the functional dependencies among the strategy map elements, based on the use of the fuzzy inference database and the Mamdani fuzzy inference method [25].

This paper is devoted to the construction of fuzzy strategic decision making models based on the formalized strategy maps.

2. Models

A multicriteria problem of optimal use of resources for the strategy implementation is being solved.

Two groups of criteria are considered: "strategic" and "economic". The degree of strategic goals' achievement is the criteria of the former group; and the indicators reflecting the need to bear the costs of resources and their economic efficiency are the criteria of the latter group. This is primarily the amount of each of the resources required to implement some set of measures. Besides, these are indicators of the change in unit costs, reflecting changes in the size and structure of the organization's current costs, and its economic efficiency resulting from the implementation of various sets of measures.

The solution is understood as a set of strategic measures (projects), the implementation of which will lead to certain "strategic" and "economic" consequences: increase in the degree of the goals' achievement, need to bear lump-sum costs of resources, and change in the economic efficiency.

Definitions and notation used in [26] will be partially used in the formal description of models.

Suppose X is the solution, $X \in D_x$, D_x is the feasible solution set. Criteria are set by *n* scalar functions that form vector $y = y_1, y_2, \ldots, y_n$, where $X \rightarrow Y = F(x)$. The optimal solution $X^0 \in D_x$ must be found.

The optimization model corresponding to this formulation looks as follows:

$$X^0 = F^{-1} \ \text{opt} Y(X) \ , \qquad (1)$$

where *opt* is the operator optimization of vector Y.

Trade-off region Γ_x is the subset of the feasible set D_x with the following property: all solutions that belong to it cannot be simultaneously improved by all local criteria. The optimal solution always belongs to trade-off region ($X^0 \in \Gamma_x$), otherwise it can be improved. As such, the search for an optimal solution can be limited to the trade-off region, which is usually much smaller than the entire feasible decision space.

The model of solution selection corresponding to this definition Γ_x can be written as follows:

$$\Gamma_x = \ X \Big| X \in D_x, \ X' \big| Y(X') \geq Y(X) \ \cap D_x = \varnothing \ , \qquad (2)$$

or

$$\Gamma_x = \bigcup_{A \in D_A} \left[F^{-1} \left[\max_{A \in D_A} \sum_j a_j Y_j(X) \right] \right], \qquad (3)$$

where $A = \ a_1, a_2, \ldots, a_n$ is the vector parameter defined on the set $D_A = \left\{ A \middle| \sum_j a_j = 1, a_j > 0 \right\}$.

The components of the vector $A = \ a_1, a_2, \ldots, a_n$ can be considered as weights of the criteria. As such, the trade-off region consists of global (and also local in the non-convex case) optima:

$$X^0 = F^{-1} \left[\max_{X \in \Gamma_x} \sum_j a_j Y_j(X) \right]. \qquad (4)$$

The efficiency of managerial solutions can be improved by using some trade-off models.

The trade-off model assumes introduction of additional criteria, the so-called fallback prices. Suppose there are two solutions X', X'' in the trade-off region and their evaluation criteria are Y_1 and Y_2, where solution X' exceeds X'' by one criterion but is inferior by another criterion. To compare these solutions, a measure of the relative decrease in the quality of the solution for each criterion (fallback price) *x* is introduced:

$$x_1 = \frac{\lambda_1 \Delta Y_1(X', X'')}{\max\limits_{X', X''} Y_1(X)}; \quad x_2 = \frac{\lambda_2 \Delta Y_2(X', X'')}{\max\limits_{X', X''} Y_2(X)}, \qquad (5)$$

where ΔY_1 and ΔY_2 are the absolute levels of criteria decline in the transition from solution X' to X'' (for Y_1) and the reverse transition (for Y_2), λ_1, λ_2 are the weights of criteria Y_1, Y_2. If $x_1 > x_2$, X' is considered the preferable solution, and vice versa.

The weights of criteria λ_1, λ_2 are set expertly and therefore can be specified in a certain linguistic scale with their subsequent translation into fuzzy numbers. Accordingly, fallback prices x_1, x_2 will be fuzzy. In this case, they should be compared by rules for comparing fuzzy numbers.

There are multicriteria problems where the criteria of one group are the objective functions to be maximized or minimized, and the other criteria are assigned norms, with achievement of all norms known to be impossible. The principle of proportional development can also be applied in the solution of such problems.

In our case, the "economic" criteria are minimized, and norms can be assigned to "strategic" criteria (degrees of the goals' achievement). Suppose they are denoted as $H_1, H_2, \ldots, H_m$. In the general case, $0 \le H_i \le 1$ (internal and external conditions have changed at some stage and, due to the realized impossibility or even inadvisability of achieving all the originally set goals, "the bar was lowered" for some goals). At the same time, the current degrees of the goals' achievement (originally equal to 0, but already nonzero at this stage) will be denoted as $b_1, b_2, \ldots, b_m$.

Condition of equality of the relative shortfalls for all goals is the objective function, which can be called the objective function of proportional development. In the general case, the objective function of proportional development can be represented as follows:

$$\frac{H_i - b_i + \Delta b_i}{H_i} k_i = \frac{H_j - b_j + \Delta b_j}{H_j} k_j \quad (i, j = \overline{1, m}) \qquad (6)$$

where k_i, k_j are the coefficients adjusting the degrees of relative shortfalls of the i-th and j-th goals based on additional conditions, Δb_i, Δb_j are the increments of the degrees of the i-th and j-th goals' achievement without the costs of the resources taken into account (self-development of the system).

The goal weights can be used as coefficients k_i, k_j. Smaller norm for goal does not necessarily mean the lesser significance of the latter. The norm can be reduced due to the inadvisability of achieving the original goal level explained by changes in internal and external conditions, but the importance of the goal itself can still remain high, i.e. the achievement of a new norm for this goal may be more important than the achievement of norms for other goals (which are closer to 1).

The degree of relative shortfalls of the i-th goal will be further understood as follows:

$$W_i = \frac{H_i - b + \Delta b_{j\ i}}{H_i} k_i . \qquad (7)$$

Each set of measures can be assigned a vector $W = W_1, W_2, \ldots, W_m$ as a result of these measures. On the one hand, the closer the degree of goals' achievement to the normative values is, i.e. the closer the components of the vector W to zero are (or the smaller the norm of the vector W, for example, its length $|W| = \sqrt{W_1^2 + W_2^2 + \ldots + W_m^2}$), the "better" some set of measures are.

On the other hand, the proportionality of development requires the minimality of the "spread" of the vector W element values. In other words, the preference of the set of measures can be determined by the value $d\ W = \max_i W_i - \min_i W_i$ (the smaller, the "better").

As such, a two-criteria problem of choosing the optimal set of measures from all possible sets arises. A trade-off region (Pareto-optimal regions) is also found for this problem, at which the final choice is made in accordance with the fair trade-off principle.

The "economic" criteria are not taken into account in the last proposed scheme of selecting set of measures (finding the optimal solution). Nevertheless, it is obvious that a solution that is slightly "better" than others by generalized "strategic" criteria ($\|W\|$, $d(W)$ may be significantly inferior to them by "economic" criteria (require substantially more resources).

In this regard, another, more complicated pattern of choice can be proposed, where the "economic" criteria are taken into account along with the generalized "strategic" criteria. First of all, a sequence (a linearly ordered set) of solutions (sets of measures) is arranged in order of priority (in descending order) by generalized "strategic" criteria (by one of them, or by both at a time, taking into account the fair trade-off principle). Each member of the sequence (solution) is assigned a number (in percent) reflecting its deviation from 0 (from an ideal solution where $\|W\|$ and/or $d(W)$ are equal to 0). The greatest possible deviation (for example, $\sqrt{m}$ for $\|W\|$ or 1 for $d(W)$) can be taken as 100%.

Then, an indifference radius is specified – a deviation value at which all solutions with smaller deviation can be considered to have equal priority (from a strategic standpoint). The choice among such solutions is made according to the "economic" criteria. Changing indifference radius, in fact, means managing the ratio (degree of preference) between the "strategic" and "economic" criteria. For a sufficiently large indifference radius (greater than the deviation of the last term of the sequence), the "economic" criteria are not applied at all. Vice versa, for a small indifference radius (smaller than the deviation of the first term of the sequence), only "economic" criteria are taken into account ("strategic" criteria are not applied).

In a more general case, the whole sequence of ranked solutions can be divided into a number of intervals with a specified interval from 0 to 100%. In this case, solutions that fall into one interval will be considered to have equal priority (from the strategic standpoint). The ranking of solutions within each interval is carried out according to the "economic" criteria. In this case, the degree of preference between the "strategic" and "economic" criteria is managed through the subinterval variation. "Strategic" criteria are not applied if the interval is 100%, and "economic" criteria are not applied if the interval is 0%.

A characteristic feature of this approach is that the two-criteria objective function is generated through the simulation procedure in this case. In a more general case, several (more than two) groups of criteria, and hence a multicriteria objective function can be considered.

The proposed crisp multicriteria problems can be transformed into fuzzy ones. For example, the coefficients adjusting the relative shortfalls of goals based on additional conditions (for example, goals' weights) can be fuzzy. The norms $H_1, H_2, \ldots, H_m$ themselves can be fuzzy as well. In this case, the relative shortfalls of goals W_i will be fuzzy. Accordingly, the objective function of proportional development will be fuzzy. It must be noted that the equality in formula (6) should be regarded as a fuzzy equality in this case. In this regard, the method of calculating the degree of fuzzy equality may differ: the formulas of Lukasiewicz, Zadeh and others can be used to calculate the fuzzy inclusion measure [24].

The norm of vector W and value $d\ W$ will be fuzzy. Accordingly, the two-criteria problem of choosing the optimal set of measures from the possible sets will be fuzzy.

It must be noted that the proposed pattern of choice, where the "economic" criteria are taken into account along with the generalized "strategic" ones, can be implemented in the fuzzy case as well. The sequence (a linearly ordered set) of solutions (sets of measures) in order of priority (in descending order) by generalized "strategic" criteria (by one of them) can be formed by the rules for comparing fuzzy numbers. If a sequence of solutions is formed by both generalized "strategic" criteria at once, then the fuzzy modification of the fair trade-off principle above described is used.

The indifference radius (or a subinterval, in general case) can also be fuzzy. In this case, the membership of the solution to a particular interval can be defined with some degree of certainty (calculated, for example, as the area of the figures cut off by the fuzzy solution membership function and straight lines parallel to the ordinate axis and passing through the boundaries of the corresponding intervals). The fuzzy solution can be assigned to an interval with the maximum degree of certainty.

3. Conclusion

In this study, we proposed fuzzy methods to solve multicriteria problems related to resources' optimal use for implementing a strategy based on formalized strategy maps. The fuzzy modifications of the trade-off model, various models of proportional development, and models where multicriteria objective functions are generated through simulation procedures are suggested. The advantages of fuzzy methods are associated with the extensive use of expert judgements in multicriteria models, especially in the strategic decision-making models. It is supposed to further develop the models for solving semi-structured strategic problems using fuzzy inference methods.

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