

Intelligent Support for Adaptive Constructing of Trajectory in Project Implementation Scenario Network



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Abstract The paper is devoted to the problems of managing the implementation of multi-scenario multi-stage projects under conditions of uncertainty, which is relevant in modern conditions. The proposed approach is based on the presentation of the project model in the form of a scenario network, the nodes of which correspond to the sets of activities of the project stage, and the arcs show the sequence of the stages. The choice of the arc along which the transition from one node to another takes place (within the framework of the trajectory on the network of scenarios) is made on the basis of an expert analysis of the results of the implementation of the measures of the next stage and external conditions at the end of the stage, which determines the adaptability of project implementation management. As a tool for analysis, it is proposed to use the methodological apparatus of L. Zadeh's theory of linguistic variables. The final selection of the transition arc (carried out as part of the adaptive construction of the project trajectory) is made by the decision maker based on the results of fuzzy inference and personal preferences. The proposed approach makes it possible to ensure multi-scenarios planning and adaptability of managing the implementation of multi-stage projects. Preliminary results of using a research prototype of an intelligent expert system for analyzing the results of the stages and adaptive construction of the project trajectory may indicate the effectiveness of the proposed approach.

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1 Introduction

In modern conditions which are characterized by a high level of instability and unpredictability of the conditions for the implementation of projects, the mechanism of adaptive management of long-term multi-stage projects [1–3] is becoming increasingly important. Such mechanism can provide the possibility of flexible respond to different changes. To the greatest extent, this applies to socio-economic projects, which are characterized by a significant fuzziness of concepts and patterns of the subject area [4], however, the effective implementation of innovative technological projects also requires adjustments during implementation [5–7].

The purpose of the article is to develop a theoretical apparatus for intelligent support for managerial decision-making in adaptive project management based on network scenario modeling and fuzzy linguistic decision-making support for choosing a project trajectory. Network models [8, 9] make possible taking into account the multiscenarity, that provides the possibility of considering various options for the implementation (trajectories on the scenario network) of the project. The aggregation of models and methods of fuzzy linguistic analysis by L. Zadeh [10] and decision support theory [11] makes it possible to use domain terminology familiar to experts when evaluating project performance indicators and environmental factors at the time of decision-making, as well as when constructing fuzzy productions that bind decision options and fuzzy statements about the conditions in which they are made.

2 Materials and Methods

2.1 Scenario Network of Project Implementation

Let us consider the project as a sequence of sets of measures, each of which represents a stage in the implementation of the project. At the same time, we believe that at the end of each (except the last) stage, it is possible to choose a subsequent set of measures depending on:

- common results of current stage and several previous stages of the project;
- complex of external factors affecting the subsequent implementation of the project.

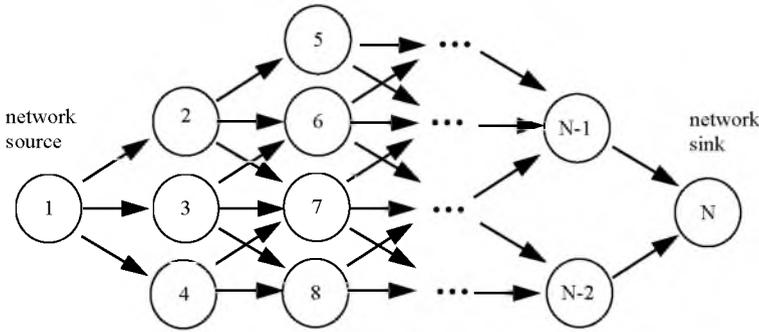


Fig. 1 Graphical representation of the project scenario network (example)

Thus, the project can be described as a network of scenarios (see Fig. 1), which is an oriented graph without loops, contours and parallel arcs with one source (vertex having zero degree of entry) and one sink (vertex having zero degree of exit).

As this takes place (as differentiated from activity-oriented network [12], where nodes and edges represent events and activities):

- the vertices of the network correspond to the complexes of activities (stages) of the project;
- the arcs connecting the vertices of the network show the sequence of completion of the complexes of activities (stages) of the project;
- the source of the network corresponds to the initial stage;
- the sink of the network corresponds to the final stage.

Thus, the trajectory of the project is the path from network source to sink.

2.2 Fuzzy Linguistic Description of Project Indicators and External Factors

Consider the system of current project performance indicators

$$IND = \langle Ind_{in}, i = -1, 2, \dots I; n = 1, 2, \dots N \rangle \tag{1}$$

and a system of external factors affecting the implementation of the following stages

$$FACT = \langle Fact_{jn}, j = -1, 2, \dots J; n = 1, 2, \dots N \rangle \tag{2}$$

where i is the number of the indicator, j is the number of the factor, n is the number of the set of activities performed at the considered stage of the project. The values of indicators and factors are assumed to be obtained as a result of direct measurement and/or expert evaluation.

Further, without loss of generality, we will assume that these quantities take values in the range from 0 to 1, which can always be achieved by reducing these quantities to a dimensionless form, for example, using the formulas:

$$\begin{aligned} \text{Ind}'_{i,n} &= \text{Ind}_{i,n} / \text{maxInd}_{i,n}, \text{Fact}'_{j,n} = \text{Fact}_{j,n} / \text{maxFact}_{j,n} \\ i &= 1, 2, \dots, I; j = 1, 2, \dots, J; n = 1, 2, \dots, N \end{aligned} \tag{3}$$

where $\text{maxInd}_{i,n}$, $\text{maxFact}_{j,n}$ —maximum possible values of indicators and factors, a $\text{Ind}'_{i,n}$, $\text{Fact}'_{j,n}$ —dimensionless values of these quantities.

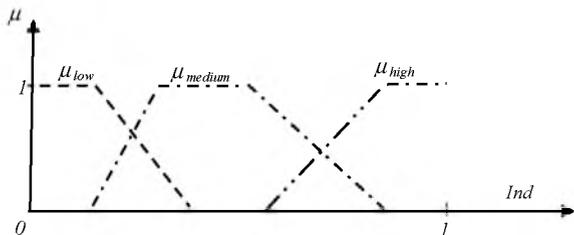
However, the use of numerical values of project indicators and external factors does not make it possible to show how significant they are for the subsequent implementation of the project. The level of significance can be determined by experts at the verbal level using the terms low, medium, high. Thus, the transition from numerical characteristics $\text{Ind}_{i,n}$, $\text{Fact}_{j,n}$ (1), (2) to corresponding linguistic variables $\text{LingInd}_{i,n}$, $\text{LingFact}_{j,n}$, whose formal description (according to [13]) has the form (4):

$$\begin{aligned} \text{LingInd}_{i,n} &= \langle \text{NameLingInd}_{i,n}, \text{Un}, \text{Tbase}, \text{G}, \text{MInd}_{i,n} \rangle \\ \text{LingFact}_{j,n} &= \langle \text{NameLingFact}_{j,n}, \text{Un}, \text{Tbase}, \text{G}, \text{MFact}_{j,n} \rangle \\ i &= 1, 2, \dots, I; j = 1, 2, \dots, J; n = 1, 2, \dots, N \end{aligned} \tag{4}$$

where NameLingInd и $\text{NameLingFact}_{j,n}$ —names of linguistic variables, that match to names of indicators and factors; $\text{Un} = [0, 1]$, $\text{Tbase} = \{\text{low}, \text{medium}, \text{high}\}$, G —common for all constructed variables universal set, the base term-set for the values under consideration; an assembly of syntactic rules that allow to generate term names from the names of the Tbase elements (which leads to the formation of the term-set, $\text{Tbase} \subseteq \text{T}$); Mind —semantic rules that establish correspondences between terms from T and fuzzy subsets of universal set Un . The membership functions of these sets can have, in particular, a trapezoidal type [14], as shown in Fig. 2.

A model description of a multi-scenario project in the form of a scenario network and a fuzzy linguistic model description of the indicators of the completed project stages, as well as environmental factors, allows the building of decisive rules and procedures for choosing a subsequent set of activities after the completion of the next stage, which is the main result of the work.

Fig. 2 Graphs of membership functions μ_{low} , μ_{medium} , μ_{high} , defining the semantics of the terms low, medium, high)



3 Results and Discussion

3.1 Decisive Rules for Choosing a Subsequent Set of Measures

In addition to the previously discussed IND indicators \mathfrak{n} and FACT factors we construct integral indicators Ind, Fact, which generally reflect the result of the implementation of the next stage of the project and the predicted external conditions for its subsequent implementation. We will assume that the numerical values of Ind, Fact are also in the range $[0, 1]$. Note that the values of the integral indicators cannot be directly measured, and to determine them, it is necessary to perform computational procedures. The weighted average formulas widely used for calculating integral indicators [15] have a significant drawback associated with the complexity of estimating the error in determining the weight coefficients by experts [16, 17]. Therefore, in accordance with the general methodology of fuzzy linguistic analysis, we construct linguistic variables LingInd, LingFact, which correspond to Ind, Fact (like it was made for $\text{Ind}_{i,n}$, $\text{Fact}_{j,n}$ and represented by relations (4)). Then we will build dependencies between partial indicators (factors) $\text{Ind}_{i,n}$, $\text{Fact}_{j,n}$ and integral indicators (factors) Ind, Fact in the form of fuzzy production rules (5), (6):

$$\begin{aligned}
 & \text{if } (\text{FInd}_{\text{low}}(\text{Ind}_{i,n}, i = 1, 2, \dots, I; n = 1, 2, \dots, N)) \text{ then } (\text{Ind} - \text{low}) \\
 & \text{if } (\text{FInd}_{\text{medium}}(\text{Ind}_{i,n}, i = 1, 2, \dots, I; n = 1, 2, \dots, N)) \text{ then } (\text{Ind} - \text{medium}) \quad (5) \\
 & \text{if } (\text{FInd}_{\text{high}}(\text{Ind}_{i,n}, i = 1, 2, \dots, I; n = 1, 2, \dots, N)) \text{ then } (\text{Ind} - \text{high}) \\
 & \text{if } (\text{FFact}_{\text{low}}(\text{Fact}_{j,n}, j = 1, 2, \dots, J; n = 1, 2, \dots, N)) \text{ then } (\text{Fact} - \text{low}) \\
 & \text{if } (\text{FFact}_{\text{medium}}(\text{Fact}_{j,n}, j = 1, 2, \dots, J; n = 1, 2, \dots, N)) \text{ then } (\text{Fact} - \text{medium}) \\
 & \text{if } (\text{FFact}_{\text{high}}(\text{Fact}_{j,n}, j = 1, 2, \dots, J; n = 1, 2, \dots, N)) \text{ then } (\text{Fact} - \text{high}) \quad (6)
 \end{aligned}$$

where FInd_{low} , $\text{FInd}_{\text{medium}}$, $\text{FInd}_{\text{high}}$, $\text{FFact}_{\text{low}}$, $\text{FFact}_{\text{medium}}$, $\text{FFact}_{\text{high}}$ —are fuzzy propositional formulas, the elements of which are fuzzy statements regarding the correspondence of numerical values of indicators $\text{Ind}_{i,n}$ and factors $\text{Fact}_{j,n}$ to the term values from the set T . Particular form of these formulas depends on the specifics of the subject area of the project and is determined by experts.

Within the framework of the proposed approach, the direct determination of numerical values can be implemented using the fuzzy inference procedure (for example, using the Mamdani algorithm [18], which has a high level of interpretability, which is important when justifying decisions).

We will assume that each of the stages of the project can have only three options as its continuation:

- an optimistic option, assuming good results of the implementation of the activities of the stage under consideration and favorable conditions for the further implementation of the project;

- the basic option, which assumes satisfactory results of the implementation of the activities of the stage under consideration and normal conditions for the further implementation of the project;
- a pessimistic option, which implies not quite satisfactory results of the implementation of the activities of the stage under consideration and unfavorable conditions for the further implementation of the project.

Let us represent the decision rules for choosing the continuation option after the k -th stage of the project implementation in the form of fuzzy production rules (7):

$$\begin{aligned}
 &\text{if } (F_{k,\text{pessim}}(\text{Ind}_p, \text{Fact}_p, p = 1, 2, \dots, k) \text{ then } (\text{Solution}_k\text{--pessimistic}), \\
 &\quad \text{if } (F_{k,\text{base}}(\text{Ind}_p, \text{Fact}_p, p = 1, 2, \dots, k) \text{ then } (\text{Solution}_k\text{--base}) \\
 &\text{if } (F_{k,\text{optim}}(\text{Ind}_p, \text{Fact}_p, p = 1, 2, \dots, k) \text{ then } (\text{Solution}_k\text{--optimistic}), \\
 &\quad k \in \{1, 2, \dots, N\}
 \end{aligned} \tag{7}$$

where $F_{k,\text{pessim}}$, $F_{k,\text{base}}$, $F_{k,\text{optim}}$ —fuzzy propositional formulas, the elements of which are fuzzy propositions regarding the correspondence of the numerical values of indicators Ind_{in} and factors Fact_{jn} to term values from set T . Particular form of these formulas depends on the specifics of the subject area of the project and is determined by experts.

3.2 Decision Support Procedure for Choosing the Next Set of Measures

To select the option to continue the project on the basis of a system of production decision rules, an iterative procedure was developed based on the use of the Mamdani algorithm without performing the last step (defuzzification). The scheme of the procedure is shown in Fig. 3.

The iterative nature of the procedure is associated with the desire to use not the entire history of the project implementation ($\text{Ind}_p, \text{Fact}_p, p = 1, 2, \dots, k$), but only a part of it ($p = k-h, \dots, k-1, k$), to find a solution, which reduces the accumulation of errors when obtaining a solution. The procedure is terminated by a decision maker (if the result satisfies it) or when the maximum possible memory depth is reached ($h = k-1$).

The final choice of the transition arc (carried out as part of the adaptive construction of the project execution trajectory), and, consequently, the choice of a set of activities performed at the next stage of the project, is made by the decision maker, based on the results of the procedure and personal preferences.

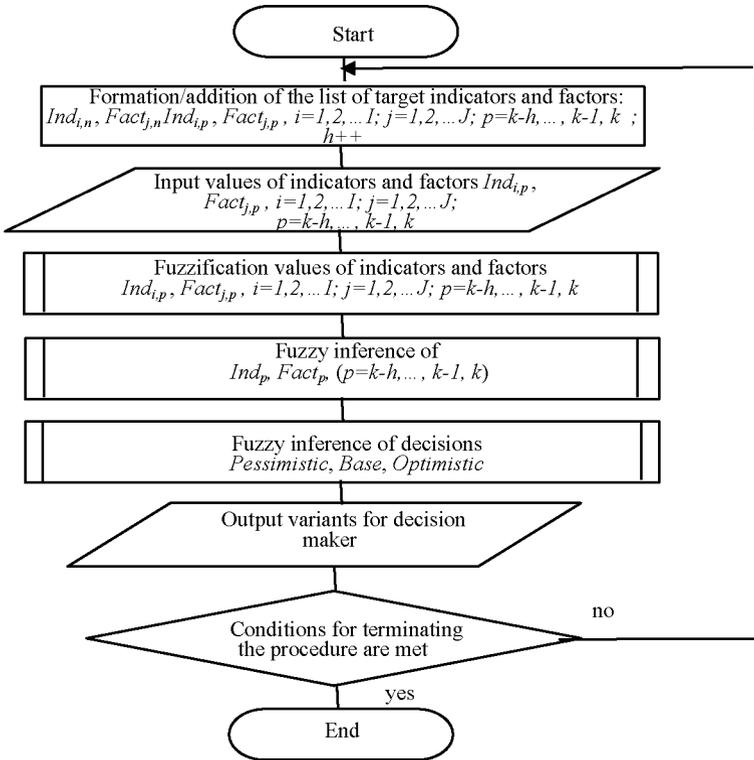


Fig. 3 An iterative procedure for determining recommended options for continuing the project

4 Conclusion

Adaptive project management (allowing you to respond flexibly to possible changes in external factors, taking into account the results obtained earlier) requires decision support tools for choosing a continuation option at each stage of the project. The approach proposed in the paper is based on the presentation of the project in the form of a scenario network, the nodes of which correspond to the sets of activities performed/to be performed at the considered stage of the project. As part of management decision support in adaptive project management, the following are built in the paper:—a set of fuzzy linguistic variables corresponding to the project indicators and external factors at the considered stage of the project:—a system of fuzzy production rules linking linguistically described indicators/factors with integral (within the considered stage) indicators/factors;—a system of decision rules for choosing the option to continue the implementation of the project based on the linguistic values of the integral indicators/factors for the previous stages;—an iterative procedure for choosing the option to continue the project, based on the use of the Mamdani fuzzy inference algorithm). The proposed approach makes it possible

to provide multi-scenario planning and adaptability of managing the implementation of multi-stage projects. Preliminary results of the application of a research prototype of an intelligent expert system for analyzing the results of the stages and adaptive construction of the project trajectory may indicate the effectiveness of the proposed approach. One of the directions for further development and use of the approach can be its application in solving the problems of synthesis of multi-scenario projects (in combination with evolutionary methods of selecting parameters [19]).

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