Fuzzy Model for the Software Projects Design Risk Analysis

Tetyana Bragina, Galina Tabunshchyk

Abstract – ***analysis of project risk, which depends on basic software risk level of projects with iterative lifecycle and software development project model are made by the authors. Fuzzy model for the project risk are proposed by the authors.***

Keywords –***risk management, software project, the response to risk, prediction.***

I. Introduction

One of the main problems, which directly influence on the software development, is that there is no single optimal model of software development process. It must be determined for each specific project and can vary over a very wide range, depending on the scale, novelty and criticality of the project, the distribution of participants, customer requirements. Depending on the selected model creating a software project can be characterized by various risks with different levels of criticality. So management practice depends on the project's model also. For effective risk management it is necessary to form a predictable object model when its limits and possible states have a fuzzy description. In this case, taking into account the fuzziness of information to construct an adequate object model for the prospective evaluation of risk is a problem that can't be solved with the existing deterministic methods of qualitative and quantitative risk analysis.

From the above, it is clear that the choice of software development process model and prediction of the project risk level are very actual problems in project management. To solve these problems, it is necessary to have mathematical tools, based on which it will be possible to determine the most relevant model of software development, the predictable level of the project risk and individual risk levels, taking into account fuzziness of input data.

II Problem Definition

Software model is usually understood as the structure that determines the execution sequence and interaction of processes, activities and tasks throughout the life cycle. The most common model with an iterative development process: Rational Unified Process, Microsoft Solutions Framework, Personal Software Process / Team Software Process and Agile (eXtreme Programming, Crystal, Feature Driven Development) [1].

Analysis of statistical data and literature [2, 3, 4] allowed to identify the main software development projects risks:

– violations of the scheduling;
– changing requirements;
– high staff turnover;
– violation of specifications;
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– low productivity;
– insufficient management attention;
– lack of staff motivation.

These risks are described by linguistic variables (Table 1).

The most critical risk for RUP is a risk of violating the scheduling (reaction to the appearance - recalculation timing of work stages), for MSF - changing requirements (reaction - re-evaluation of the project each time the requirements are added or changed), for Agile - high staff turnover (reaction - to take into account estimates of labour costs on training staff involved at the initial stage of an excessive number of participants). The proposed reaction would reduce the negative impact of risks on the ultimate projects goals and will execute the project on time with a given budget [1].

At the planning stage for effective risk management is necessary to collect expert opinions regarding the risks that may arise in the creating software process and analysis for each of them. The next step is to process these data to assess the overall level of project risk, which will determine whether a given level of risk acceptable to the customer's software project and the head of the development team, and also allow to choose the model of software development best suited to this particular project. To solve this problem is needed a model for software projects risk analysis.

The model adopted for the risk analysis should take into account the uncertainty of parameters describing observed process, as it directly affects the accuracy of prediction, effectiveness of design solutions. When making decisions, a software project manager has to deal with fuzzy, heterogeneous information, and qualitative information in the description of objects may take precedence over quantity. As a consequence, some information that can be used to predict risk, using traditional methods (statistics, expert) may be considered poor, with insufficient accuracy and an incomplete for prediction.

Table 1. Linguistic variables that determine the project risk

Linguistic variable	Universal set	Evaluation terms
Violations of the scheduling, x1	0 – 100 % (increase of calendar terms in% from the initial planning)	Low, middle, high
Changing requirements, x2	0 – 100 % (increase of claims in% from the initial planning)	

High staff turnover, x3	0 – 1 (the ratio of retired employees to the initial number of staff)
Violation of specifications, x4	0 – 1 (probability of violations of specifications)
Low productivity, x5	0 – 100% (reduction in the planned mid-level performance)
Insufficient management attention, x6	0 – 100% (reduction of the required level of project management)
Lack of staff motivation, x7	0 – 100 % (reduction of staff interest)

Using the methods of fuzzy inference in conjunction with traditional methods it will increase the validity of decisions taken by the software project manager. Fuzzy model will effectively manage the projected object risks when its boundaries and the possible states have a fuzzy description.

III FUZZY LOGIC INTERFERENCE FOR RISK DEFINITION

Fuzzy production models are the most common type of fuzzy models that are used to describe, analyse and simulate complex systems and processes. These models can be used to construct prediction systems, the input of which receives information about possible values of parameters describing the process and the output provides information about the predictive value of risk. One of the important requirements of the predictive system is the accuracy of prediction. One of the important conditions for predictive accuracy is the choice of model, that is the condition of the adequacy of mathematical models of the phenomenon.

When using fuzzy object model prediction can be constructed by designing and settings fuzzy knowledge bases, which are set of linguistic statements like [5]:

$$\text{if } x1 \in A1 \text{ and } x2 \in A2 \text{ and } \ldots, \text{ then } y \in B, \tag{1}$$

where xi - input variables, y – output variable, {Ai} and B – fuzzy terms are defined for {xi} and y.

Expert knowledge A → B reflects the fuzzy causal relationship premise and conclusion, so it can be called a fuzzy relation and denote by R: R = A → B, where «→» is called a fuzzy implication.

The ratio R can be regarded as a fuzzy subset of the direct product X × B full set of assumptions X and conclusions B. In such a way the process of obtaining a fuzzy inference result B' using this observation A' and knowledge A → B can be represented as compositional rules: B'= A'• R = A'• (A → B), where «•» - convolution operation.

Membership function of fuzzy set B' can be represented as:

$$\mu_{B'}(y) = \sup_{x \in X} \{\mu_{A'}(x) T \mu_R(x,y)\} \tag{2}$$

where T - operation T-norm; $\mu_R(x,y)$ - membership function of fuzzy relations R, which is regarded as a fuzzy subset of the direct product X × Y complete set of assumptions X and conclusions Y.

The most common method of inference in fuzzy systems - it's fuzzy inference with the use Mamdani mechanism.

In Mamdani mechanism used minimax composition of fuzzy sets. This conclusion is in the Mamdani algorithm form can be mathematically described as follows [5]:

1. Fuzzification: there are degrees of truth for the preconditions of each rule

$$\mu_{jp}(x_i^*), \tag{3}$$

where i=1,2…n, j=1,2…m, p=1,2,…kj.

2. The logical conclusion: there are the levels of "truncated" to the preconditions of each rule (using the minimum operation):

$$\mu_j(y) = \min_{i,p} \mu_{jp}(x_i^*), \tag{4}$$

where i=1,2…n, j=1,2…m, p=1,2,…kj.

Then there are "truncated" functions for the output variable:

$$\mu_j'(y) = \min(\mu_j(y), \mu_{d_j}(y)). \tag{5}$$

3. Composition: using the operations MAX (max) produced the union of the found truncated functions, which leads to obtaining the final fuzzy subset for the output variable with membership function:

$$\mu(y) = \max_j(\mu_j'(y)), \tag{6}$$

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

4. Defuzzification –in order to find y*. Usually carried out by the centroid method.

For defuzzification the received output variables, there are many approaches[5]. However, their use is limited to the case of fuzzy sets of the first kind. In the case of P-fuzzy sets with membership function of interval type for defuzzification can be used:

– MOM – mean of maximum:

$$y^* = \frac{1}{|MAX(\mu)|} \sum_{y \in MAX(\mu_Y(y))} y \tag{7}$$

where $MAX(\mu_Y(y)) = \{y \in Y \mid \forall y' \in Y : \mu_Y(y') \le \mu_Y(y)\}$ – a set of the output variable values for which the membership function takes the maximum value, this set must be nonempty; $MAX(\mu)$ – number of elements $MAX(\mu_Y(y))$;

–LOM – largest of maximum:

$$y^* = \max(MAX(\mu_Y(y))) \tag{8}$$

–SOM – smallest of maximum:

$$y^{*}=\min(MAX(\mu_{Y}(y))) \quad (9)$$

– maximum membership function:

$$y=\arg\sup_{y} \mu_{B}^{CP}(y), \quad (10)$$

where $\mu_{B}^{CP}(y)$ – average membership function of P-fuzzy sets.

Feature of using fuzzy production models for solving the problem of risk management and getting his prospective evaluation consists in an opportunity for the input fuzzy model of the object R is not a fixed point values of the vector $X^{*}=(x_1^{*},x_2^{*},...,x_n^{*})$, and the interval, since the expert easier to determine the value of this parameter in the form of an interval $[\underline{x},\overline{x}]$, whose borders – lower and upper bounds, respectively:

$$X^{*}=[(\underline{x}_1^{*},\overline{x}_1^{*}),(\underline{x}_2^{*},\overline{x}_2^{*}),...,(\underline{x}_n^{*},\overline{x}_n^{*})].$$

Using the above relations, presented approach allows the vector of input variables

$$X^{*}=[(\underline{x}_1^{*},\overline{x}_1^{*}),(\underline{x}_2^{*},\overline{x}_2^{*}),...,(\underline{x}_n^{*},\overline{x}_n^{*})],$$

associate a decision about the value of risk, i.e.

$$X^{*}=[(\underline{x}_1^{*},\overline{x}_1^{*}),(\underline{x}_2^{*},\overline{x}_2^{*}),...,(\underline{x}_n^{*},\overline{x}_n^{*})]\to r_j\in RP=(r_1,r_2...r_m). \quad (11)$$

Representing on the input of the fuzzy model R interval value of the input parameter, as output we get interval value functions for the respective linguistic variable. In this case, we consider a P-fuzzy set [6], each value of membership function which is not a point but a fixed interval [0, 1] and in general can be written as

$$\mu_A(x):X\to 2^{[0,1]}. \quad (12)$$

To assess the linguistic variable "risk" RP will be used the term-set that determines the probability of risk occurrence:

{r1 - HIGH, r2 - MIDDLE, r3 - LOW }.

It should be noted that the algebra of P-fuzzy sets is a boolean algebra and for fuzzy sets, which change the level of supplies, the operation of intersection and union are defined as [6]

$$\mu_{A\cap B} = [\min\{r_1(x), s_1(x)\}, \min\{r_2(x), s_2(x)\}] = [\underline{\mu_C}(x), \overline{\mu_C}(x)]; \quad (13)$$

$$\mu_{A\cup B}=[\max\{r_1(x),s_1(x)\},\max\{r_2(x),s_2(x)\}]=[\underline{\mu_M}(x),\overline{\mu_M}(x)], \quad (14)$$

where $[r_1(x),s_1(x)]$ – interval estimates of the parameter x membership function to fuzzy set A; $[r_2(x),s_2(x)]$ – interval estimates of the parameter x membership function to fuzzy set B; $[\underline{\mu_C}(x),\overline{\mu_C}(x)]$ – interval estimates of the parameter x membership function to fuzzy set C, $C=A\cap B$; $[\underline{\mu_M}(x),\overline{\mu_M}(x)]$ – interval estimates of the parameter x membership function to fuzzy set M, $M=A\cup B$.

An estimate of risk is obtained by solving fuzzy logic equations. These equations are obtained based on a matrix system of logical propositions, and let us calculate the values of membership functions of solutions for interval values of model input parameters.

IV BASE OF RULES FOR FUZZY INTERFERENCE

Consider the example to forecast the project risk evaluation using the direct method of fuzzy inference. Section 2 dealt with the following key risks inherent in almost all projects: violation of scheduling, changing requirements, staff turnover, the violation of specifications, low productivity, insufficient management attention, lack of staff motivation.

These risks and their influence on the project will vary depending on the model of software project. Consider the effect of combination of these risks on the overall project risk.

Model structure for determining the project risk assessment can be represented as

$$RP=f_{RP}(x_1,x_2,x_3,x_4,x_5,x_6,x_7) \quad (15)$$

In accordance with [7], knowledge of the relationship for RP can be presented as a table 2, where L - short for "LOW", M - "MIDDLE", H - "HIGH".

Table 2. Expert knowledge of the relationship between project risk and the individual components

Risk	**RUP**					
	L	**L**	**M**	**M**	**H**	**H**
x_1	L	M	C	H	M	H
x_2	L	M	M	L	H	M
x_3	L	M	H	M	H	M
x_4	L	L	M	L	M	H
x_5	M	L	H	L	M	L
x_6	M	H	M	L	M	L
x_7	M	H	M	M	L	M
Risk	**MSF**					
	L	**L**	**M**	**M**	**H**	**H**
x_1	L	M	H	L	M	L
x_2	L	L	M	H	H	M
x_3	M	M	L	M	M	H
x_4	L	L	M	L	M	H
x_5	M	L	H	M	L	L
x_6	M	L	M	L	M	L
x_7	H	M	M	H	H	M
Risk	**Agile**					
	L	**L**	**M**	**M**	**H**	**H**

x_1	L	M	L	H	L	H
x_2	M	M	H	M	H	M
x_3	L	M	M	L	M	H
x_4	H	L	M	L	M	H
x_5	L	M	L	L	H	L
x_6	L	L	M	L	H	M
x_7	M	L	M	H	M	H

Based on the Mamdani mechanism of fuzzy inference, combine the fuzzy output for each rule with the composition. Using the above table in accordance with Eqs. (4), (5), (6) write a system of logical equations relating the membership function of solutions about the project risk value and the variables affecting it:

– for RUP

$$\begin{aligned}\mu^{H}_{RUP}(r_1) &= \mu^{M}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{H}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{H}(\underline{x}_3^*,\overline{x}_3^*)\cap\\ &\cap\mu^{M}(\underline{x}_4^*,\overline{x}_4^*)\cap\mu^{M}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{M}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{L}(\underline{x}_7^*,\overline{x}_7^*)\cup\\ &\cup\mu^{H}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{M}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{M}(\underline{x}_3^*,\overline{x}_3^*)\cap\mu^{H}(\underline{x}_4^*,\overline{x}_4^*)\cap\\ &\cap\mu^{L}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{L}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{M}(\underline{x}_7^*,\overline{x}_7^*)\end{aligned}$$

$$\begin{aligned}\mu^{M}_{RUP}(r_2) &= \mu^{M}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{M}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{H}(\underline{x}_3^*,\overline{x}_3^*)\cap\\ &\cap\mu^{M}(\underline{x}_4^*,\overline{x}_4^*)\cap\mu^{H}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{M}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{M}(\underline{x}_7^*,\overline{x}_7^*)\cup\\ &\cup\mu^{H}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{L}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{M}(\underline{x}_3^*,\overline{x}_3^*)\cap\mu^{L}(\underline{x}_4^*,\overline{x}_4^*)\cap\\ &\cap\mu^{L}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{L}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{M}(\underline{x}_7^*,\overline{x}_7^*)\end{aligned}$$

$$\begin{aligned}\mu^{L}_{RUP}(r_3) &= \mu^{L}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{L}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{L}(\underline{x}_3^*,\overline{x}_3^*)\cap\\ &\cap\mu^{L}(\underline{x}_4^*,\overline{x}_4^*)\cap\mu^{M}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{M}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{M}(\underline{x}_7^*,\overline{x}_7^*)\cup\\ &\cup\mu^{M}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{M}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{M}(\underline{x}_3^*,\overline{x}_3^*)\cap\mu^{L}(\underline{x}_4^*,\overline{x}_4^*)\cap\\ &\cap\mu^{L}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{H}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{H}(\underline{x}_7^*,\overline{x}_7^*)\end{aligned}$$

– for MSF

$$\begin{aligned}\mu^{H}_{MSF}(r_1) &= \mu^{M}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{H}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{M}(\underline{x}_3^*,\overline{x}_3^*)\cap\\ &\cap\mu^{M}(\underline{x}_4^*,\overline{x}_4^*)\cap\mu^{L}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{M}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{H}(\underline{x}_7^*,\overline{x}_7^*)\cup\\ &\cup\mu^{L}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{M}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{H}(\underline{x}_3^*,\overline{x}_3^*)\cap\mu^{H}(\underline{x}_4^*,\overline{x}_4^*)\cap\\ &\cap\mu^{L}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{L}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{M}(\underline{x}_7^*,\overline{x}_7^*)\end{aligned}$$

$$\begin{aligned}\mu^{M}_{MSF}(r_2) &= \mu^{H}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{M}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{L}(\underline{x}_3^*,\overline{x}_3^*)\cap\\ &\cap\mu^{M}(\underline{x}_4^*,\overline{x}_4^*)\cap\mu^{H}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{M}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{M}(\underline{x}_7^*,\overline{x}_7^*)\cup\\ &\cup\mu^{L}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{H}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{M}(\underline{x}_3^*,\overline{x}_3^*)\cap\mu^{L}(\underline{x}_4^*,\overline{x}_4^*)\cap\\ &\cap\mu^{M}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{L}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{H}(\underline{x}_7^*,\overline{x}_7^*)\end{aligned}$$

$$\begin{aligned}\mu^{L}_{MSF}(r_3) &= \mu^{L}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{L}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{M}(\underline{x}_3^*,\overline{x}_3^*)\cap\\ &\cap\mu^{L}(\underline{x}_4^*,\overline{x}_4^*)\cap\mu^{M}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{M}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{H}(\underline{x}_7^*,\overline{x}_7^*)\cup\\ &\cup\mu^{M}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{L}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{M}(\underline{x}_3^*,\overline{x}_3^*)\cap\mu^{L}(\underline{x}_4^*,\overline{x}_4^*)\cap\\ &\cap\mu^{L}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{L}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{M}(\underline{x}_7^*,\overline{x}_7^*)\end{aligned}$$

– for Agile

$$\begin{aligned}\mu^{H}_{Agile}(r_1) &= \mu^{L}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{H}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{M}(\underline{x}_3^*,\overline{x}_3^*)\cap\\ &\cap\mu^{M}(\underline{x}_4^*,\overline{x}_4^*)\cap\mu^{H}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{H}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{M}(\underline{x}_7^*,\overline{x}_7^*)\cup\\ &\cup\mu^{H}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{L}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{H}(\underline{x}_3^*,\overline{x}_3^*)\cap\mu^{H}(\underline{x}_4^*,\overline{x}_4^*)\cap\\ &\cap\mu^{L}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{M}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{H}(\underline{x}_7^*,\overline{x}_7^*)\end{aligned}$$

$$\begin{aligned}\mu^{M}_{Agile}(r_2) &= \mu^{L}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{H}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{M}(\underline{x}_3^*,\overline{x}_3^*)\cap\\ &\cap\mu^{M}(\underline{x}_4^*,\overline{x}_4^*)\cap\mu^{L}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{M}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{M}(\underline{x}_7^*,\overline{x}_7^*)\cup\\ &\cup\mu^{H}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{M}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{L}(\underline{x}_3^*,\overline{x}_3^*)\cap\mu^{L}(\underline{x}_4^*,\overline{x}_4^*)\cap\\ &\cap\mu^{L}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{L}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{H}(\underline{x}_7^*,\overline{x}_7^*)\end{aligned}$$

$$\begin{aligned}\mu^{L}_{Agile}(r_3) &= \mu^{L}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{M}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{L}(\underline{x}_3^*,\overline{x}_3^*)\cap\\ &\cap\mu^{H}(\underline{x}_4^*,\overline{x}_4^*)\cap\mu^{L}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{L}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{M}(\underline{x}_7^*,\overline{x}_7^*)\cup\\ &\cup\mu^{M}(\underline{x}_1^*,\overline{x}_1^*)\cap\mu^{M}(\underline{x}_2^*,\overline{x}_2^*)\cap\mu^{M}(\underline{x}_3^*,\overline{x}_3^*)\cap\mu^{L}(\underline{x}_4^*,\overline{x}_4^*)\cap\\ &\cap\mu^{M}(\underline{x}_5^*,\overline{x}_5^*)\cap\mu^{L}(\underline{x}_6^*,\overline{x}_6^*)\cap\mu^{L}(\underline{x}_7^*,\overline{x}_7^*)\end{aligned}$$

V The Membership Function Calculation for the Main Types of Risk

Next we define the membership function for fuzzy terms of fuzzy production model input parameters xi. To illustrate, consider the definition of membership function for variable x1 - violation of the scheduling. This variable is defined on the universal set U(x1) = (0 – 100 %) using fuzzy terms

T (xi) = (low, middle, high).

There are direct and indirect methods for constructing membership functions [7].

Using direct methods expert sets for each x value of μ(x). For a specific object expert, based on the reduced scale, gives μA (x) ∈ [0, 1], forming a vector membership function {μA(x1), μA(x2), ..., μA(xn)}.

Indirect methods for determining the values of membership functions are used in cases where there is no measurable basic properties, which are determined by a fuzzy set. Typically, this method of paired comparisons. If the value of membership functions are known, for example, μA (xi) = wi, i = 1, 2, ..., n, then pairwise comparisons can be represented by the matrix relations A = {aij}, где aij = wi / wj.

Using direct methods were obtained expert data regarding the level of membership functions for each of the major risks.

To configure the settings used 120 training data and 20 control data, uniformly selected from the input ranges. Following quality of approximation was applied [8]:

$$APE = \frac{1}{P}\sum_{i=1}^{P}\frac{T(i)-O(i)}{|T(i)|}\times 100\%, \quad (16)$$

where P – number of pairs of data, T(i) and O(i) is the i-th desired and predicted output, respectively. The average error in the determination of membership functions 16,9 %.

Approximation of the expert opinions on risk x1 - violations of scheduling can be represented by a piecewise linear membership functions [5], namely the triangular functions:

$$\mu^M(x_1) = \begin{cases} 0, x_1 \le a \\ \frac{x_1-a}{b-a}, a<x_1<b \\ \frac{c-x_1}{c-b}, b\le x_1<c \\ 0, c\le x_1 \end{cases}, \quad (17)$$

where a=0, b=50, c=100.

$$\mu^L(x_1) = 1 - x_1/100; \quad (18)$$

$$\mu^H(x_1) = x_1/100. \quad (19)$$

Changing requirements, x2 corresponds to a trapezoidal function:

$$\mu^M(x_2) = \begin{cases} 0, x_2<a \\ \frac{x_2-a}{b-a}, a\le x_2<b \\ 1, b\le x_2\le c \\ \frac{d-x_2}{d-c}, c<x_2\le d \\ 0, d<x_2 \end{cases}, \quad (20)$$

where a=0, b=25, c=50, d=75.

$$\mu^L(x_2) = 1 - x_2/100; \quad (21)$$

$$\mu^H(x_2) = x_2/100. \quad (22)$$

High staff turnover, x3 is best displayed by the symmetric Gaussian function (for the middle risk level) and linear S and Z-shaped functions (high and low risk, respectively):

– the symmetric Gaussian function:

$$\mu^M(x_3) = e^{-\frac{(x_3-b)^2}{2a^2}}, \quad (23)$$

where a=0,15, b=0,5.

– the Z-shaped functions:

$$\mu^L(x_3) = \begin{cases} 1, x_3\le a \\ \frac{b-x_3}{b-a}, a<x_3<b \\ 0, b\le x_3 \end{cases}, \quad (24)$$

where a=0,1, b=0,9.

– the S-shaped functions:

$$\mu^H(x_3) = \begin{cases} 0, x_3\le a \\ \frac{x_3-a}{b-a}, a<x_3<b \\ 1, b\le x_3 \end{cases}, \quad (25)$$

where a=0,1, b=0,9.

Violation of specifications, x4 best fit U-shape function (for the middle risk level) and linear S and Z-shaped function (for high and low risk, respectively):

– U-shape function:

$$\mu^M(x_4) = \frac{1}{1+e^{-a(x_4-b)}} * \frac{1}{1+e^{-c(x_4-d)}}, \quad (26)$$

where a=0,15, b=0,45, c=0,55, d=0,85.

– the Z-shaped functions:

$$\mu^L(x_4) = \begin{cases} 1, x_4\le a \\ \frac{b-x_4}{b-a}, a<x_4<b \\ 0, b\le x_4 \end{cases}, \quad (27)$$

where a=0,1, b=0,9.

– the S-shaped functions:

$$\mu^H(x_4) = \begin{cases} 0, x_4\le a \\ \frac{x_4-a}{b-a}, a<x_4<b \\ 1, b\le x_4 \end{cases}, \quad (28)$$

where a=0,1, b=0,9.

Low productivity (x5), insufficient management attention (x6), lack of staff motivation (x7) - all of these risks correspond to the generalized bell-shaped function (for the middle level of risk) and linear S and Z-shaped functions (for high and low risk, respectively):

– the generalized bell-shaped function:

$$\mu^M(x_5, x_6, x_7) = \frac{1}{1+\left|\frac{x-c}{a}\right|^{2b}}, \quad (29)$$

where a=15, b=2, c=50.

– the Z-shaped functions:

$$\mu^{L}(x_5,x_6,x_7)=\begin{cases}1, x\le a\\ \frac{b-x}{b-a}, a<x<b\\ 0, b\le x\end{cases}, \quad (30)$$

where a=15, b=85.

– the S-shaped functions

$$\mu^{H}(x_5,x_6,x_7)=\begin{cases}0, x\le a\\ \frac{x-a}{b-a}, a<x<b\\ 1, b\le x\end{cases}, \quad (31)$$

where a=15, b=85.

For example, the value of membership function x1 = [27; 34] for the corresponding fuzzy terms have the form:

$\mu^{H}(\underline{x}_1,\bar{x}_1)=[0,27;0,34]$,

$\mu^{M}(\underline{x}_1,\bar{x}_1)=[0,54;0,68]$,

$\mu^{L}(\underline{x}_1,\bar{x}_1)=[0,66;0,73]$.

Similarly, using the presented algorithm can be found the values of membership functions for all linguistic variables that determine the risk value. Interval values of membership functions of input parameters xi are presented in Table 3. Input parameters (the value of risk) are produced by collecting and averaging expert data of the estimated probability of risk.

Table 3 - Interval value of membership function of models input parameters xi

Risk, x_i	The risk value (probability of occurrence)	Evaluation terms		
		low (L)	middle (M)	high (H)
x_1	[27; 34]	[0,66; 0,73]	[0,54;0,68]	[0,27;0,34]
x_2	[13; 22]	[0,78;0,87]	[0,52;0,88]	[0,13;0,22]
x_3	[0,2; 0,33]	[0,71;0,88]	[0,25;0,64]	[0,13;0,29]
x_4	[0,3; 0,4]	[0,63;0,75]	[0,96;0,98]	[0,25;0,38]
x_5	[50; 60]	[0,36; 0,5]	[0,84;1,00]	[0,5;0,64]
x_6	[43; 70]	[0,4;0,79]	[0,24;0,95]	[0,21;0,6]
x_7	[55; 62]	[0,33;0,43]	[0,71;0,99]	[0,57;0,69]

Define the membership function of linguistic variable RP evaluation terms r1, r2, r3. Substitute in the system of logical equations that relate the membership functions solutions about the value the project risk and the variables affecting it, the value of membership function:

– for RUP

$\mu^{H}{}_{RUP}(r_1)=[0.54,0.68]\cap[0.13,0.22]\cap[0.13,0.29]\cap$
$\cap[0.96,0.98]\cap[0.84,1.00]\cap[0.24,0.95]\cap[0.33,0.43]\cup$
$\cup[0.27,0.34]\cap[0.13,0.22]\cap[0.25,0.64]\cap[0.25,0.38]\cap[0.36,0.5]\cap$
$\cap[0.4,0.79]\cap[0.71,0.99]=[0.13,0.22]$

$\mu^{M}{}_{RUP}(r_2)=[0.54,0.68]\cap[0.52,0.88]\cap[0.13,0.29]\cap$
$\cap[0.96,0.98]\cap[0.5,0.64]\cap[0.24,0.95]\cap[0.71,0.99]\cup$
$\cup[0.27,0.34]\cap[0.78,0.87]\cap[0.25,0.64]\cap[0.63,0.75]\cap[0.36,0.5]\cap$
$\cap[0.4,0.79]\cap[0.71,0.99]=[0.25,0.34]$

$\mu^{L}{}_{RUP}(r_3)=[0.66,0.73]\cap[0.78,0.87]\cap[0.71,0.88]\cap$
$\cap[0.63,0.75]\cap[0.84,1.00]\cap[0.24,0.95]\cap[0.71,0.99]\cup$
$\cup[0.54,0.68]\cap[0.52,0.88]\cap[0.25,0.64]\cap[0.63,0.75]\cap[0.36,0.5]\cap$
$\cap[0.21,0.6]\cup[0.57,0.67]=[0.24,0.73]$

– for MSF

$\mu^{H}{}_{MSF}(r_1)=[0.54,0.68]\cap[0.13,0.22]\cap[0.25,0.64]\cap$
$\cap[0.96,0.98]\cap[0.36,0.5]\cap[0.24,0.95]\cap[0.57,0.67]\cup$
$\cup[0.66,0.73]\cap[0.52,0.88]\cap[0.13,0.29]\cap[0.25,0.38]\cap[0.36,0.5]\cap$
$\cap[0.4,0.79]\cap[0.71,0.99]=[0.13,0.29]$

$\mu^{M}{}_{MSF}(r_2)=[0.27,0.34]\cap[0.52,0.88]\cap[0.71,0.88]\cap$
$\cap[0.96,0.98]\cap[0.5,0.64]\cap[0.24,0.95]\cap[0.71,0.99]\cup$
$\cup[0.66,0.73]\cap[0.13,0.22]\cap[0.25,0.64]\cap[0.63,0.75]\cap[0.84,1.00]\cap$
$\cap[0.4,0.79]\cap[0.57,0.67]=[0.24,0.34]$

$\mu^{L}{}_{MSF}(r_3)=[0.66,0.73]\cap[0.78,0.87]\cap[0.25,0.64]\cap$
$\cap[0.63,0.75]\cap[0.84,1.00]\cap[0.24,0.95]\cap[0.57,0.67]\cup$
$\cup[0.54,0.68]\cap[0.78,0.87]\cap[0.25,0.64]\cap[0.63,0.75]\cap[0.36,0.5]\cap$
$\cap[0.4,0.79]\cap[0.71,0.99]=[0.25,0.64]$

– for Agile

$\mu^{H}{}_{Agile}(r_1)=[0.66,0.73]\cap[0.52,0.88]\cap[0.25,0.64]\cap$
$\cap[0.96,0.98]\cap[0.5,0.64)\cap[0.21,0.6])\cap[0.33,0.43]\cup$
$\cup[0.27,0.34]\cap[0.52,0.88]\cap[0.13,0.29]\cap[0.25,0.38]\cap[0.36,0.5]\cap$
$\cap[0.24,0.95]\cap[0.57,0.67]=[0.21,0.43]$

$\mu^{M}_{Agile}(r_2) = [0.66,0.73] \cap [0.13,0.22] \cap [0.25,0.64] \cap$

$\cap [0.96,0.98] \cap [0.360,0.5] \cap [0.24,0.95] \cap [0.71,0.99] \cup$

$\cup[0.27,0.34]\cap[0.52,0.88]\cap[0.71,0.88]\cap[0.63,0.75]\cap[0.36,0.5]\cap$

$\cap[0.4,0.79]\cap[0.57,0.67]=[0.27,0.34]$

$\mu^{L}_{Agile}(r_3) = [0.66,0.73] \cap [0.52,0.88] \cap [0.71,0.88] \cap$

$\cap [0.25,0.38] \cap [0.36,0.5] \cap [0.4,0.79] \cap [0.71,0.99] \cup$

$\cup[0.54,0.68]\cap[0.52,0.88]\cap[0.25,0.64]\cap[0.63,0.75]\cap[0.84,1.00]\cap$

$\cap[0.4,0.79]\cap[0.33,0.43]=[0.25,0.43]$

VI DEFUZZIFICATION METHOD FOR RISK ASSESSMENT

Data obtained from defuzzification are analyzed to determine the most appropriate for software development model. For this model

$$\mu^{H}(r_1) = \min(\mu^{H_1}(r_1), \mu^{H_2}(r_1),..., \mu^{H_n}(r_1)), \quad (32)$$

$$\mu^{L}(r_3) = \max(\mu^{L_1}(r_3), \mu^{L_2}(r_3),..., \mu^{L_n}(r_3)), \quad (33)$$

where n – number of considered models. In the event of a dispute analyzed the level of membership functions $\mu^{M}(r_2)$.

If this risk level is unacceptable for the project manager, it is recommended to clarify the individual project characteristics and to use the proposed methods of reducing the most critical risks level.

For defuzzification was selected the approach to define the maximum average value of membership function (Eq. (7)).

Define the membership function average value of P-fuzzy sets for each type of models:

– for RUP

$\mu^{H}_{RUP}(r_1) = [0.13,0.22] = 0.17$,

$\mu^{M}_{RUP}(r_2) = [0.25,0.34] = 0.25$,

$\mu^{L}_{RUP}(r_3) = [0.24,0.73] = 0.49$;

– for MSF

$\mu^{H}_{MSF}(r_1) = [0.13,0.29] = 0.21$,

$\mu^{M}_{MSF}(r_2) = [0.24,0.34] = 0.29$,

$\mu^{L}_{MSF}(r_3) = [0.25,0.64] = 0.45$;

– for Agile

$\mu^{H}_{Agile}(r_1) = [0.21,0.43] = 0.32$,

$\mu^{M}_{Agile}(r_2) = [0.27,0.34] = 0.31$,

$\mu^{L}_{Agile}(r_3) = [0.25,0.43] = 0.34$.

In such a way, for this example, usage of any of these models will give a low risk level, but the best model is RUP, as the using this model corresponds to the maximum average value of membership function risk is LOW (0,49) and minimum average value of membership risk is HIGH (0,17). Less suitable model is Agile, as the using this model corresponds to the maximum average value of membership function risk is HIGH (0.32) and minimum average value of membership risk is LOW (0,34).

For this example, the usage of RUP, as the model most consistent with the requirements of the project, turned out to be a critical risk violation of specifications. According to the submitted recommendations it is necessary to sign the contract between the customer and the company with a description of input and output conditions, risk assessment by independent experts.

Thus, collected in the work expert knowledge help to create a base of production rules and to determine the membership functions of the main risks levels. Applying the Mamdani method of fuzzy inference to these data, we have been identified predictive project risk assessment, using information available at the stage of qualitative and quantitative analysis. Risk level is determined by analyzing all the risks, i.e. factors affecting the project efficiency, depending on the selected model software to develop a software project.

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VII CONCLUSIONS

Software development models and risk classification was carried out by the authors. Project risk analysis based on main software projects risks and fuzzy interference was performed in the paper.

The Mamdani fuzzy interference algorithm was used for software projects with an iterative lifecycle risk assessment. Membership functions for each of the software projects risks, identified in the project, which allows to predict the project risk level in pre-planning were defined.