MODELING RESEARCH PROJECT RISKS WITH FUZZY MAPS

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Abstract: *The authors propose a risks evaluation model for research projects. The model is based on fuzzy inference. The knowledge base for fuzzy process is built with a causal and cognitive map of risks. The map was especially developed for research projects, taken into account their typical lifecycle. The model was applied to an e-testing research project: the probability of not obtaining quality results was computed considering the over-budget sum and the quality level of research idea. The computed risk is situated on the highest level in risks map. A software system for evaluating risks in e-testing research project was also developed. The research was funded by the Ministry of Education and Research, National University Research Council, Grant PCE_ID_873.*

Key words: *risk management; research project; model; fuzzy logics; risks map*

1. Introduction

Identifying, prioritizing and treating risks represent common management activities. For a long time, hazard risks, as well as financial ones have been actively managed. But, the variety, number and interactions between risks are continually increasing. The operational and strategic risks have increased due to the failure of the control mechanisms in a very dynamic business environment. In these circumstances, the organizations admit the importance of managing all risks, both the standard and the new risks.

Different organizations, such as: rating agencies, stock exchanges, institutional investors, shareholders, and corporate governance induced an external pressure to the company management for managing risks systematically and comprehensively. One solution is to adopt the portfolio approach, the company management considering the portfolio risk as the risk to the entire organization. The risks are managed considering the implications for the whole company, in a holistic approach.

There is a growing tendency to quantify risks. The risk quantification allows managers to develop "what if" scenarios and make informed decisions. Advances in technology and expertise have made the quantification possible. Despite real advances, there will always remain risks that are not easily quantifiable, such as those related to human intervention and the newer ones. There is a continuing effort to quantify the portfolio risks, based on the individual risks and the interactions quantification. This can be extremely difficult if a high degree of precision is required. But, this is not usually the case.

Over time and with practice, companies become more familiar with and more capable of managing risks, and even seeking out opportunities to assume risks. Companies understood that informed risk-taking is a means to competitive advantage.

2. Research projects management

The research project management is full of uncertainty and complexity. Research has elements of creativity and innovation and accurate prediction of the research outcome is therefore very difficult. It is the research project manager job to manage both the complexities stemming from the culture(s) of researchers/research work and the uncertainties associated with generating research results [4][3].

The research project managers should make the following statement to the project team members: "If you do not have several failures, you are not doing a good job" [7]. Researchers acting safe are more likely to produce conservative and expected results. In order to obtain innovative results, the researchers should have a risk-taking behavior, increasing the probability of failure. This behavior should be a characteristic at the research system, even at the individual level, it is expected that the researcher will seek to avoid failure. In the majority of research projects, the purpose of project management is also to avoid such failures. It is an apparent conflict between the need for predictability of project output, "on time" and "on budget" and the unpredictability of research outcome and new research opportunities arising in the course of the project. Usually, the quality of output may improve if deviations from plan are allowed.

The researchers ask a large degree of autonomy in their work and democracy in decision making. They co-operate in a research project, but, in the same time, they are strongly competing each others to obtain credit for the results generated in the project, such as: authorship of conference contributions or articles, patents. This competition may lead to conflict between the joint goals of the co-operation and individual goals of researchers.

In addition, the relationship between the research project manager and the project participants is characterized by an asymmetric distribution of knowledge where individual researchers know a lot more about the potential – negative and positive – of their research contributions than the project manager does ([4]).

3. Risks modeling methods

According the manner in which the calculations are carried out, there are analytic and simulation methods for risk modeling. The *analytic methods* require a set of assumptions, especially related to the probability distributions. The *simulation methods* require a large number of “trials” to approximate an answer. They are relatively robust and flexible, can accommodate complex relationships and depend less on simplifying assumptions and standardized probability distributions. Considering the manner in which the relationships among variables are represented, there are statistical and structural methods. The *statistical methods* are based on observed statistical qualities of random variables without regard to cause/effect relationships while *the structural methods* are based on explicit cause/effect relationships. Figure 1 presents the most important risk models developed using this methods, with their advantages.

Calculation technique / Representation of the relationships	Analytic *(closed-form formula solutions)*	Simulation *(solutions derived from repeated “draws” from the distribution)*
Statistical *(based on observed statistical qualities without regard to cause/effect)*	Statistical-analytical models *(speed, easy replication, use of available data)* **Example**: RBC	
Structural *(based on specified cause/effect linkages; statistical qualities are outputs, not inputs)*		Structural simulation models *(flexibility; complex relationships, incorporation of decision processes, scenario drivers examination)* **Example**: DFA

Figure 1. The risk model classes (source: [2])

The methods used to model the risks are usually customized according to the specific risks which occurred in the company. There are a wide variety of methods that can be applied to model risks. According the extent to which they rely on historical data or expert input ([2]), they are lying in a continuum of the sources information (figure 2).

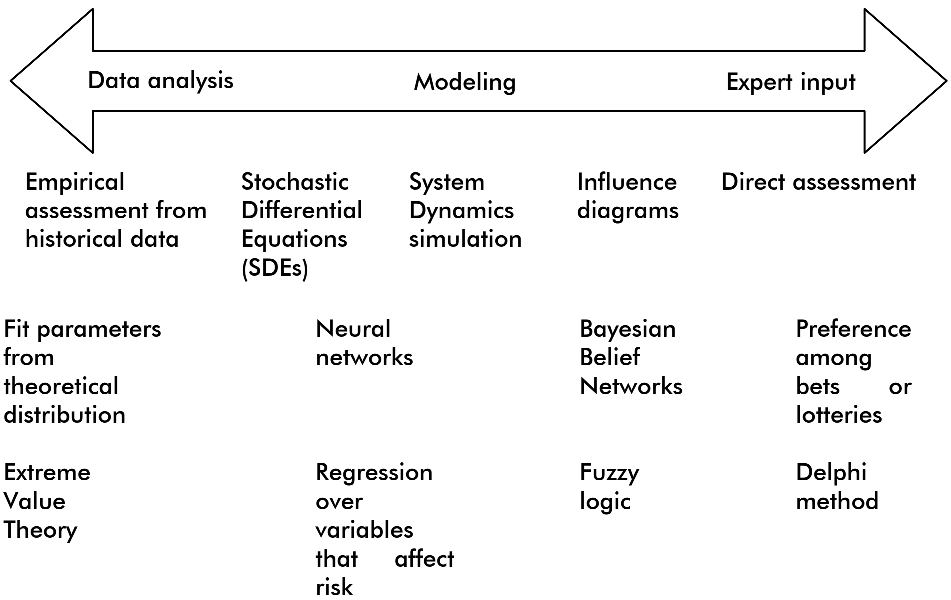

Figure 2. The continuum of methods for risk modeling

Although there are numerous techniques for risk modeling, more and more experts are afraid to use them for making precise risk estimations. Fuzzy representations are a solution to obtain realistic risks assessments in projects management [3], within certain limits. A fuzzy abordation for risk modeling can be improved by considering causal and cognitive risks mapping [1], which are diagrams reflecting cause-effect relations within projects.

4. Fuzzy Model for Risk Evaluation in Research Projects

The proposed fuzzy model brings a solid contribution to risk management by adapting existent techniques in risks evaluation to research projects. The model has two important stages: risk identification from an expert database, using risk maps and building model components for fuzzy inference. The model allows risk quantification by knowing the crisp values of risk sources. Thanks to fuzzy logics mechanisms, the result has a higher estimation value.

4.1. Risks Identification using Causal and Cognitive Maps

A common approach in project risks identification is considering the risks source: management, cost, technology, production, environment or schedule. The fuzzy model considers risks not only in correlation with their source, but in correlation with project lifecycle, too [1]. "While it is futile to try to eliminate risk, and questionable to try to minimize it, it is essential that the risks taken be the right risks." [5]

It si known that research projects are highly risky: in research project, the added value should be as high as possible and should be obtained as quickly as possible. [8] For better managing risks, it is useful to create a causal and cognitive map of risks, based on experts experience [1]. This map describes the propagation of risks throughout the project. Risks occurred at a certain moment of project lifecycle (see Fig. 3) will create other risks in the following moments. Risks are felt during all phases of a research project: idea conceptualization, project proposal development, project funding source, project initiation, project execution and project closing down.

Figure 3. Research Project Lifecycle

Starting from the research project lifecycle (Fig.4), following risks are identified:

- environmental risks: lack of interest on the market, precarious economic situation, unfavorable legislation;
- management risks: unrealistic duration estimation, poor negotiation capacities, poor planning, unclear objectives, poor communication, poor control, misunderstood overall vision, behind- schedule risk, acceptance of a poor idea, loss of a good idea;
- financial risks: unrealistic budget estimation, over-budget risk;
- production & technology: poor innovation capacities, lack of experienced collaborators, multidisciplinary implications, lack of quality results, low embedded quality of the idea;

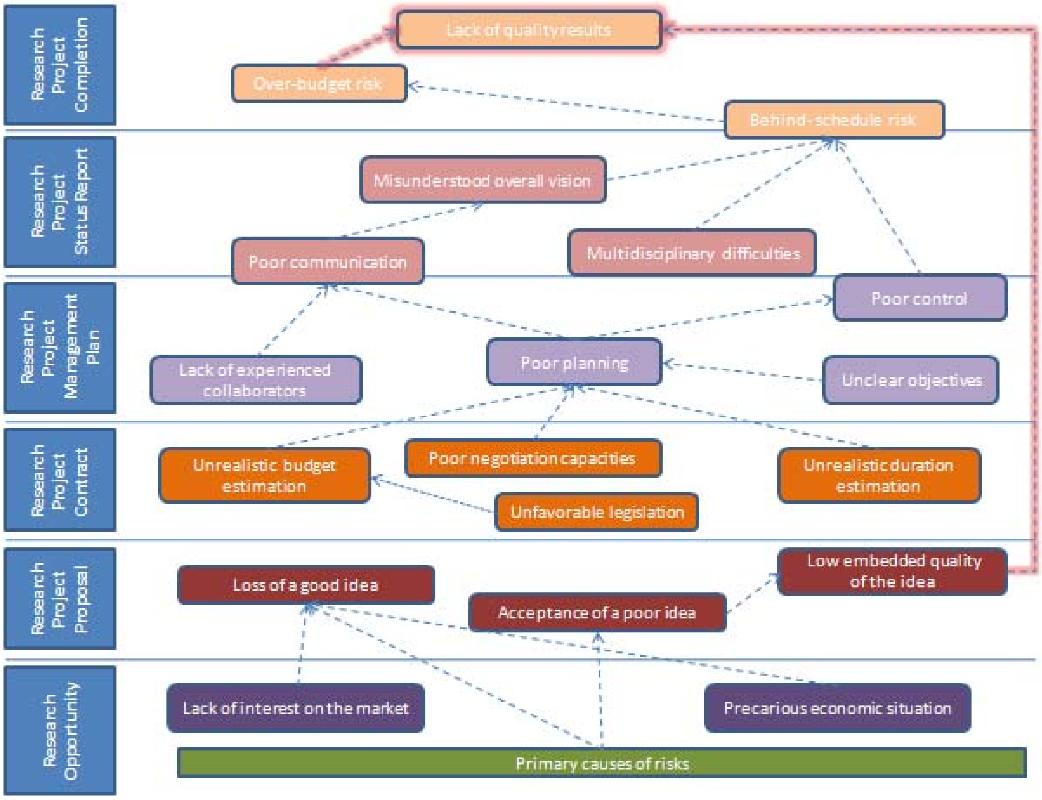

Figure 4. Risks Propagation Map in Research Projects

After creating the risks propagation map, it is also useful to create a risks register or a risks log, in which each identified risk from the map should have a code, a name, a description and a source (type). A fragment of such a register is shown in Table 1. The identified risks are the knowledge base for creating the fuzzy model rules.

Table 1. Fragment of Risks Register in Research Projects

Risk Code	Risk Name	Risk Description	Risk Type
RSK01	Low embedded quality of the idea	The accepted idea can't be properly developed.	Production & Technology
RSK02	Over-budget risk	The project is behind schedule and extra budget is necessary for finishing the research.	Financial

4.2. Model Components for Fuzzy Inference

The proposed model for risk evaluation in research projects has the typical components of a fuzzy model [9]: input variables, output variable, fuzzy rules. The rules used in fuzzy risks modelling are built on the two well-known concepts from risks management (probability of risk occurance and impact of it on project development) and on primary causes of risks, identified in the risks map. The model can be generally stated as: „The more over-budget is and the more embedded quality of the research idea, the lower the degree of risk encountered in the research project." The risk situated at the highest level of the map was the only one taken into account when stating the model, because of the transitivity principle in risk propagation chain. In fact, the model consists from a set of rules used in defining project risks, which are incorporated in "Lack of quality results" risk. The model can be applied to calculate the value of any risk represented in risks map, using numerical values of its factors. An interesting situation, specific to research projects, is the fact that the presence of an inner risk (over-budget) diminishes the over-all risk of having poor quality results.

Usually fuzzy models are used in decision making and they offer two types of answers: the risk can be either accepted or rejected [6]. The proposed model offers only a quantitative value of risk, because the decision of accepting the risk is taken by the human agent: project manager, risks manager or any other stakeholder. In conclusion, the output of the developed model isn't a form of decision, but an important parameter to make a proper decision. The model components are further described, using fuzzy formalization [9].

4.2.1. Input Variables

The model has two forms of input variables: input functions and input constants.
Input functions have the form of:

P(Rsk) = probabily of Rsk occurance
I(Rsk) = impact of Rsk on research project
where Rsk = considered risk code

They are described in Table 2, according to fuzzy logics concepts.

Table 2. Input Variables Description in Risk Analysis Model

Fuzzy Variable Name	Universe of Discourse	Linguistic Grades
P(Rsk)	[0,100] %	VL(very low), L(low),M(medium), H(high), VH(very high)
I(Rsk)	[0, 50]	VL(very low), L(ow),M(medium), H(high), VH(very high)

Input constants have the form of:

RskCause1 = cause 1 of Rsk occurance
RskCause2= cause 2 of Rsk occurance
where Rsk = considered risk code

They are described in the same manner as input functions, the only difference being the defined universe of discource: it is specific to each identified cause.

4.2.2. Output Variables

The output variable is the value for an identified risk and is notated as:

V(Rsk) = quantitative value of Rsk, where Rsk = considered risk code

It is described in Table 3 and graphically represented in Fig. 5. In fact, both input and output variables can be graphically represented by fuzzy sets: on Ox axis the value of fuzzy variable is represented and on Oy axis the value of μ (function of belonging to a fuzzy set) is represented. The "triangles" are fuzzy sets.

Table 3. Output Variables Description in Risk Analysis Model

Fuzzy Variable Name	Universe of Discourse	Linguistic Grades
V(Rsk)	[0, 10]	VL(very low), L(ow),M(medium), H(high), VH(very high)

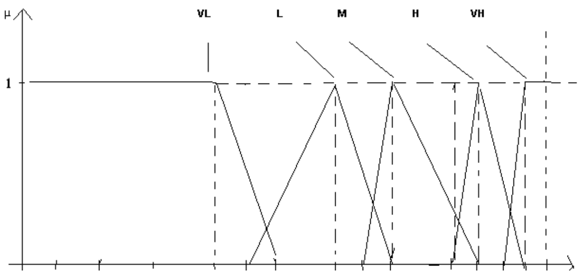

Figure 5. Fuzzy Sets Representation for Risk Value in Research Projects

4.2.3. Model Rules

The risk evaluation model consists from a set of predefined rules for establishing risks value in research projects. These inference rules are mentioned in Table 4. The connective used to bind conditions in rules is "and". Besides the linguistic values of model variables (VL, L, M, H and VH), some restrictors are used:

- "somewhat"= $\sqrt[3]{\mu}$
- "very"= μ^2

where μ is the function showing if a numeric value belongs to a fuzzy set and it has values between 0 and 1 (a greater value shows a stronger membership).

Table 4. Inference Rules for Analysis Risk "Rsk" in Research Projects

P(Rsk)/ I(Rsk)	VL	L	M	H	VH
VL	VL	somewhat VL	L	somewhat M	very H
L	L	L	L	H	VH
M	M	M	M	H	VH
H	H	H	H	very H	VH
VH	VH	VH	VH	H	very VH

An example of a rule is (R1):

(R1): if P(Rsk) is H and I(Rsk) is VH then Rsk is VH

The interpretion of rule (R1) is:

If risk Rsk has a high probability of occurance and the impact of this risk is very high, then its value is also very high. (See the underlined values from Table 4)

5. Application of the Fuzzy Model to Evaluate Risks in an E-testing Research Project

The fuzzy model for risks evaluation is validated by applying it to a real research project. The project has the main goal of studying e-testing methods in e-learning environments and of discovering and improving those which has applicability in project management. Among research objectives, there are: education in a globalized society, e-learning in present times, tools for implementing e-learning systems, defining the place of e-testing in e-learning platforms, development of an e-testing model suitable for knowledge evaluation in project management field. Being a research project, the quality of the final results depends on the quality of the research idea and on budget constraints (see the highlighted elements from Figure 4). The risk of having a poor quality idea has attached a number of points (from 0 to 10), reflecting the level of innovation and applicability of the idea. The risk of having a low quality idea as the starting point of the project depends on the risk of accepting that idea. Over-budget risk is a well-known risk in projects, but in research projects it can add value to scientific results, thus enhancing the satisfaction level of the stakeholders.

5.1. Formalization of Risk Evaluation Model for E-testing Research Project

In order to compute the probability of "Lack of quality results" risk (notated "P(Rsk)"), low embedded quality of the idea is reflected in "LowQAIdea" variable and over-budget sum in "OverBudget" variable. Both variables are defined in Table 5. Inference rules for showing the effect of "LowQAIdea" and "OverBudget" changes on "Rsk" value are presented in Table 6.

Table 5. Fuzzy Variables for Computing Risk in E-testing Research Project

Fuzzy Variable Name	Variable Type	Universe of Discourse	Linguistic Grades
OverBudget	input	[0,5] thousands of Euros	VL, L, M, H, VH
LowQAIdea	input	[0,10] points	VL, L, M, H, VH
P(Rsk)	output	[0,100]%	VL, L, M, H, VH

Table 6. Inference Rules for Computing "P(Rsk)" in E-testing Research Project

OverBudget / LowQAIdea	VERY LOW	LOW	MEDIUM	***HIGH***	***VERY HIGH***
VERY LOW	somewhat M	somewhat M	L	VL	very VL
LOW	H	H	L	VL	VL
MEDIUM	VH	H	M	***L***	***L***
HIGH	VH	VH	H	***M***	***M***
VERY HIGH	VH	VH	VH	M	M

Membership functions of input variables are illustrated in Fig. 6 and 7 and the one for output variable in Fig. 8.

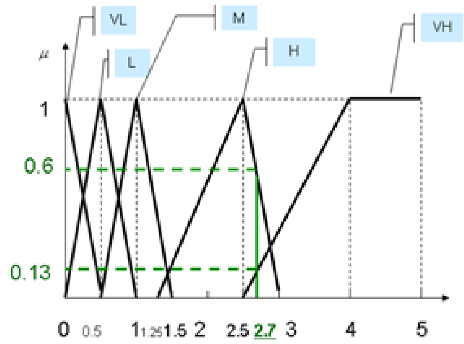

Figure 6. Membership Functions for “Over-budget” variable in Evaluating Research Project Risk

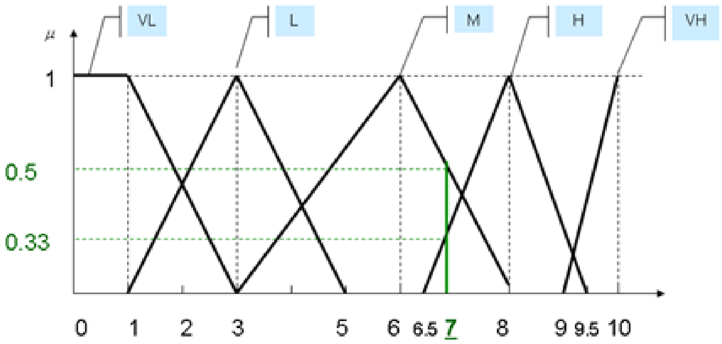

Figure 7. Membership Functions for “Low embedded quality of the idea” variable in Evaluating Research Project Risk

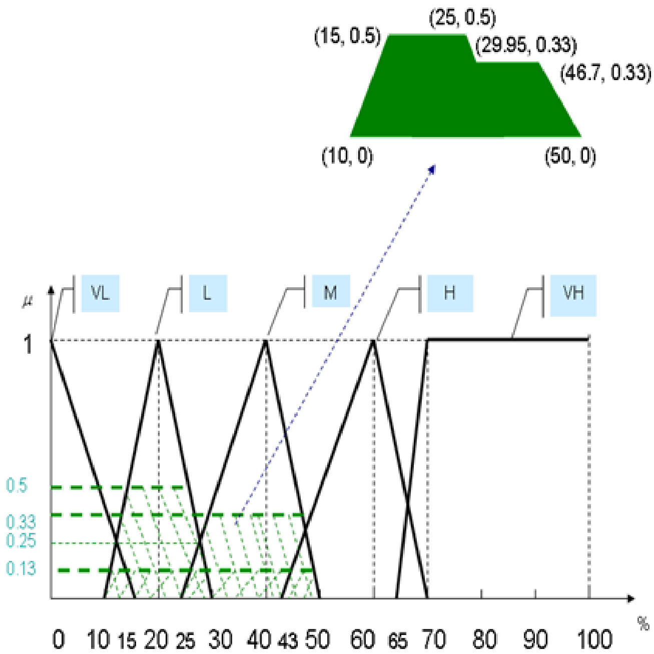

Figure 8. Membership Functions for Fuzzy Output Variable in Evaluating Research Project Risk

5.2. Steps in Applying the Risk Evaluation Model in E-testing Research Project

The fuzzy model transforms the input values to output value, in four steps. For exemplification purposes, two numerical values are considered as input values in risk evaluation model of an e-testing research project.

Step 1: Insert values for input variables

OverBudget = 2.7 (the research needs an extra sum of 2,7 thousands Euros to be finished)

LowQAIdea = 7 (the risk of having a low quality idea is 7/10, according to experts)

Step 2: Classify crisp input values in suitable fuzzy set: they gain semantic meaning.

According to Fig. 6, the over-budget sum can be high and very high. According to Fig. 7, the risk of a poor idea can be medium or high.

Step 3: Establishes membership level of each input value to a fuzzy set; an input value can belong to one or two fuzzy sets, but in a different proportion, named "trust level"; this trust level is the Oy value of the intersection point between input singleton and fuzzy set. [9] Trust level is calculated using the following formula:

$$trustLevel_x(A) = b.y + m(x - b.x) \quad \text{(F1)}$$

where *a* and *b* are two successive points from a fuzzy set, *m* is the slope of the line determined by these two points, A represents a fuzzy set and *x* represents an input value;

For LowQAIdea:

$$trustLevel_7(M) = 0.5$$

$$trustLevel_7(H) = 0.33$$

For OverBudget:

$$trustLevel_{2.7}(H) = 0.6$$

$$trustLevel_{2.7}(VH) = 0.13$$

Following sentences are considered:

(S1) "An idea of medium quality is the starting point in e-testing research project."

(S2) "An idea of high quality is the starting point in e-testing research project."

(S3) "The over-budget used in e-testing research project is high."

(S4) "The over-budget used in e-testing research project is very high."

According to above calculated trust levels, (S1) has a 50% value of truth, (S2) has 33% value of truth, (S3) a 60% value of truth and (S4) a 13% value of truth.

Step4: Apply inferences rules, in 4 stages. The resulted fuzzy sets are "cut" by a horizontal line. This line is determined by the minimum of the trust levels. Intersections between fuzzy sets and lines are obtained: this intersection has, usually, a trapezoidal shape. In the end, the reunion of "cut" fuzzy sets is made (see Fig. 8)

Step5: Restrictors (*very*, *somewhat*) are applied, if necessary.

Step6: Two defuzzification methods are applied to the final fuzzy set. Two similar values for over-all risk in e-testing project should be obtained.

In Centre of Gravity (COG) Defuzzification, the final fuzzy set is decomposed in simple shapes: triangles, rectangles and trapezes, as shown in Fig. 9. For calculating the probability of risk occurrence, the following formula is used:

$$P(Rsk)_{COG} = \frac{\sum_i center_{fig(i)} area_{fig(i)}}{\sum_i area_{fig(i)}} \qquad \text{(F2)}$$

where *fig* is the shapes vector, $center_{fig(i)}$ is the center of gravity of a figure and $area_{fig(i)}$ is the area of a figure.

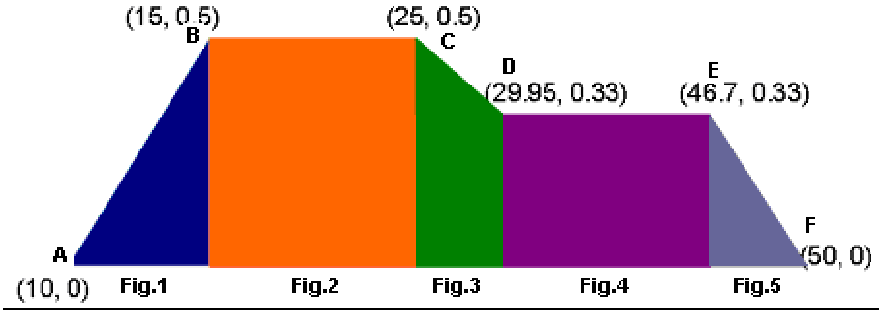

Figure 9. COG Defuzzification in Risk Evaluation Model

According to COG method, the probably of risk "Lack of quality results" for the considered input values is:

$$P(Rsk)_{COG} = \frac{13.33*1.25+20*5+28.05*2.05+38.33*5.53+47.8*0.54}{1.25+5+2.05+5.53+0.54} \Rightarrow$$

$$P(Rsk)_{COG} = \frac{16.67+100+57.7+212+25.81}{14.37} \Rightarrow$$

$$P(Rsk)_{COG} = 28.68\%$$

In Middle of Maximum (MOM) Defuzzification, the following formula is used:

$$P(Rsk)_{MOM} = \frac{\sum_i locMax_i^x locMax_i^y}{\sum_i locMax_i^y} \qquad \text{(F3)}$$

where $locMax_i^y$ is the Oy value of a local maximum (see Fig. 10), $locMax_i^x$ is the Ox value of a local maximum point and *locMax* is the vector of local maximum points.

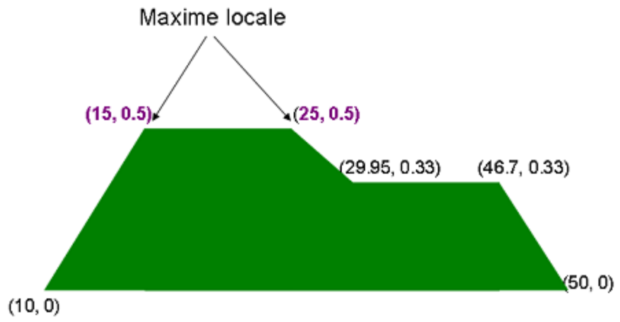

Figure 10. MOM Defuzzification in Risk Evaluation Model

According to MOM method, the probably of risk "Lack of quality results" for the considered input values is:

$$P(Rsk)_{MOM} = \frac{0.5*15+0.5*25}{0.5+0.5} \Rightarrow P(Rsk)_{MOM} = 20\%$$

The two defuzzification methods revealed similar results (28,68% and 20%): the applied model is validated. The membership function of output variable is analyzed (see Fig. 8) and the conclusion is that the "Lack of quality results" risk has a low probability of occurance for an e-testing research project.

5.3. Software for Risk Evaluation based on Fuzzy Model

The fuzzy model for analyzing the over-all risk in the e-testing research project was used to develop a fuzzy system. A Windows based application was created. The interface is intuitive (see Fig. 11): the end user has to insert the value of "over-budget" risk and of "low embedded quality of the idea" risk and will obtain the probability of over-all risk occurrence in the e-testing research project.

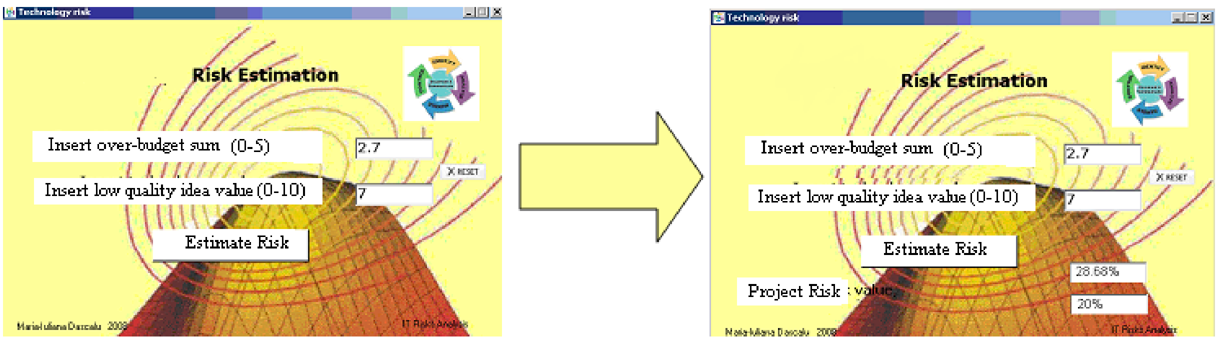

Figure 11. Software Product for Risk Evaluation Model in E-testing Research Project

The algorithm used to create the software reflects entirely the steps described in current paper. Three specific classes are used to implement the algorithm (see Fig. 12):

- FuzzySystem: it contains the inference rules;
- FuzzySet: it contains defuzzification methods, union, intersection, restrictor functions;
- FuzzyPoint: elements of fuzzy sets;

FuzzySystem class has to be changed, in order to create other fuzzy systems.

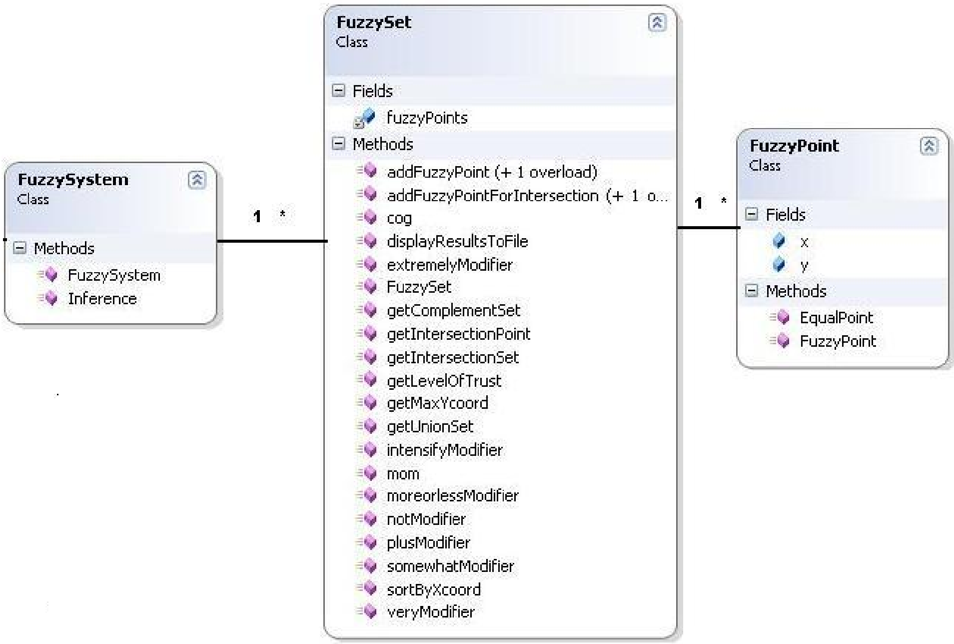

Figure 12. Class Diagram for Fuzzy Risk Evaluation System

6. Conclusions

The proposed model offers an easy-to-use tool for risk evaluation in research projects. The model lies on fuzzy inference. The knowledge base used by fuzzy rules is built on causal and cognitive maps of risks. Although research projects are known for their high level of risk, very few dedicated risk systems were developed especially for them. Therefore, the fuzzy model for risk evaluation in research projects is an innovative instrument which can be used to forecast project failure: stakeholders can save money, time, effort, without giving up the quality of predictions. The model was used to develop a software system for evaluating risk in an e-testing research project, so its applicability was validated. The system can be further developed to evaluate all risks from the map, not only the one from the highest level, as it does now.

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