

## RESEARCH AND DEVELOPMENT PROJECTS FUZZY DEFINITION IN THE UNIVERSITY CONTEXT

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**Abstract.** *Purpose* – research on R&D projects implemented at universities shows that many researchers feel that the requirements set on R&D project definition in the process of calls for projects brake the innovativeness and the freedom of research. Thus, the objective of the paper is to propose a soft, fuzzy set based method of R&D project definition, which would allow to evaluate projects in the stage of project calls, but at the same time would not act contrary to the research ideas of the most ingenious and innovative researchers.

*Research methodology* – the proposal is based on the results of over 70 structured interviews with R&D project managers from Polish and French universities. The respondents expressed their critical opinion about the required definition of R&D projects in the application stage of most calls, suggested which elements should be improved and in which way. Most of them criticised the required detail level of projects description and emphasized the uncertainty present in their research. Then we propose to model this uncertainty by means of fuzzy sets.

*Findings* – the result of the research presented in the paper is a new way of R&D project definition, based on the fuzzy theory, adjustable to each R&D project type. The new method of project definition will express the actual uncertainty and innovative potential of each R&D project and thus allow a selection of R&D projects which would maximise their contribution to the university and science development.

*Research limitations* – the proposed approach needs to be validated and verified on the basis of a big sample of a real world R&D project, with the participation of a representative sample of researchers. Another limitation is a highly probable resistance against such an approach among the researchers and research funding institutions, as it requires a deep analysis of the planned research and its context.

*Practical implications* – it is proposed that the method will be used by research funding institutions in project calls. This will increase the efficiency of financial resources spent on research, in terms of value-added per one dollar invested in the research.

*Originality/Value* – the proposed method is the first approach to project definition based on fuzzy numbers and one of very few existing approaches to project definition taking uncertainty into account.

**Keywords:** R&D project, project definition, project chart, R&D project objective, R&D project agility.

**JEL Classification:** O332, O221, O222.

**Conference topic:** Contemporary Organizations Development Management.

### Introduction

R&D activities are inherently linked to uncertainty. While doing research, we are asking questions to which we naturally do not know answers beforehand, we are searching for substances which do not exist yet and of which it is not known whether they can be created, or for archaeological findings of which we do not know whether they have been preserved and if they have, where they are located. We try to prove theorems of which we do not know whether they are true and try to construct machines with functionalities of which we do not know whether they are really able to be achieved.

The scientific literature proposes several approaches of dealing with project uncertainty. Many of them are based on mathematical modelling of project duration and other project quantitative attributes (e.g. Pérez et al., 2016; Bordley et al., 2019), many on soft, sociological procedures (e.g. Böhle, Heidling, & Schoper, 2016; Vaagen, Borgen, &

Hansson, 2016) or on managerial methods, e.g. project complexity reduction (Floriciel, 2016). However, none of them refers to the stage of project definition for the purposes of application for funds.

Naturally, R&D activities need financial resources, and often in substantial quantities. Researchers apply for them in project calls, using forms which they have to fill in in such a way that the reviewers are persuaded that their projects deserve funding. They have to present their projects exactly according to the imposed format. This format requires them to specify the research objectives, methods and research tasks. But these elements are often not completely known or cannot be described precisely before the project is actually started. Thus a researcher who applies for money has three alternatives:

- he or she describes uncertain elements of his or her projects as if they were certain, hoping that they will be accomplished to a sufficient degree in order to get the final report accepted by respective authorities,
- he or she does the research without funding and applies in the moment when the results are already ready,
- he or she does not apply at all, feeling that the application forms and generally the calls are too narrow for the innovation and uncertainty inherent in their projects.

The objective of the research is thus to suggest a method of R&D project definition (in the university context) to be used in the phase of calls for R&D projects. This method should allow the applicants to convey the uncertainty related to their projects and, on the other hand, the experts of the funding institutions to evaluate this uncertainty properly, at the background of the potential scientific value added of the future project results.

Firstly, we show the state of art of the research on uncertainty in R&D projects and the results of our research where researchers expressed their opinion about the high uncertainty inherent in their projects. Then we propose a change in the application forms. The application procedure for R&D funding should encourage researchers to apply for highly innovative projects, projects which open completely new research directions, and which should be funded in spite of their uncertainty. Thus, the application forms should not make the applicants pretend they are sure their uncertain objectives will be attained, because they know that if they tell the truth, the application will not pass (in most calls for R&D projects, the evaluators have to use the criterion “feasibility of the objectives”, but in many innovative projects the feasibility of the objectives may be rather unclear before the project actually begins). Also, the researchers have to name explicitly the research tasks they will perform and the research methods they will use, and they have to do so even if they cannot really know which tasks and methods will be necessary, useful or possible. We illustrate the problem and the proposed approach by means of a real world case study. We close our paper with some conclusions.

## 1. Uncertainty in R&D projects – state of art

So called traditional project management (PMI, 2018, Wysocki, 2014) sets that projects should be defined according to certain rules. For example, the project goals should be described according to the SMART principle: they should be Specific, Measurable, Attainable, Realistic and Time-related. These principles have proven to be useful for e.g. engineering projects. However, it has to be underlined that generally R&D projects differ substantially from engineering projects. In the latter the goal (e.g. building a bridge) can and should be defined specifically (we know exactly what kind of bridge will be built), in a measurable way (all the bridge elements are measured), it is sure that the goal is attainable (the engineers know the bridge can be constructed), also the engineering knowledge assures that such a goal is realistic and for the same reason the time needed to build a bridge can be estimated (certain tolerances are allowed, but still the project duration can be calculated fairly exactly). If we deal with huge delays in construction projects, they are usually due rather to human than to engineering problems. The traditional project management principles also require the list of project tasks to be defined, with resources and deadlines assigned, etc. – in short, detailed planning should be done before the project is started.

In R&D projects (but also in many IT projects) the situation is more complex. It is difficult to imagine that the invention of the wheel could have happened within a project with a SMART objective. Of course, this example is exaggerated, but many of the most valuable R&D projects follow a rather fuzzy goal, which may be achieved or not, and even if it is achieved, the final form of the project product is often difficult to predict and may differ strongly from the initial plans. Also, an exact plan, with a complete list of project tasks scheduled on the time axis, is in many R&D projects simply impossible to be produced beforehand. Many research activities can be undertaken only after experiments and their form or even their possibility to be performed depend strongly on the unknown experiment result. R&D activities are by their mere nature very different from engineering activities.

In the literature various project typologies are considered, various project typology criteria are used. One of them is the presence and source of uncertainty with respect to the project goal and the methods to achieve it. (Shenhar, 2001) and (Kuchta & Skowron, 2015) has introduced the following project classification:

Table 1. Project classification (Kuchta & Skowron, 2015)

Project type	A	B	C	D
Project goal well defined before the project start	yes	no	no	yes
Methods to achieve the goal well defined the project start	no	yes	no	yes

In Table 1 we can see that there are four types of projects. The mentioned example of a bridge project would belong to category D. In projects of types A, B, C not both the elements of the couple “project goal/methods to achieve the goal” are well defined. In these projects, we may not know the ultimate goal, and even if we do know it, we may not know which methods will lead us to the (maybe still unknown) goal. Many R&D (and IT projects) are of A, B or C type.

In Kuchta et al. (2015) we can find results of research on Polish R&D projects where the percentage of R&D projects in various domains of science and in various types of research institutions are given in which the ultimately achieved goal was different from the planned one.

Table 2. Percentage of R&D projects where the achieved goal was the same/different as/from the planned one (Kuchta et al., 2015)

	Fields of science						Institution	
	The humanities and social sciences	Economic sciences	Life sciences	Medical sciences	Mathematical, physical, chemical, and Earth sciences	Technical sciences	Institutions implementing pure research	Institutions implementing applied research and experimental development
Another goal (%)	0.64	0.82	0.88	0.47	0.50	0.61	0.67	0.41
Identical goal (%)	0.36	0.18	0.13	0.47	0.40	0.35	0.31	0.53

We can notice in Table 2 that the percentage of R&D projects achieving a different goal than the planned one is relatively high. The exact numbers depend on the field of research and the type of research institutions. Especially high value of non-achievement of the original project goal can be noticed in life sciences (88% of projects). These results show that it may be very limiting to expect from a researcher to define his or her research goal in an exact way in the phase of applying for financing.

## 2. Uncertainty in R&D projects – research results

We interviewed 70 managers of R&D projects, implemented at Polish or French universities. The in depth interviews were based on an interview sheet. Two questions in the sheet referred to the uncertainty in R&D projects: in one question the interviewees were asked about the features that, according to them, distinguish R&D projects from e.g. engineering projects and in another one about the exactness/stability/certainty of the goals of their projects. 80% of interviewees indicated a substantially high degree of uncertainty at the moment of project defining. Here are the most representative statements, together with the project domain (one statement may represent more projects, in case of similar statements a representative one was selected):

- “There is high uncertainty in R&D project definition because it is unknown how big the actual sample used in experiments will be” (medicine, economy);
- “An exact definition of the expected project product is impossible because it depends on the results of the experiments” (biology, telecommunication);
- “Project goals have to be formulated prudently, in a rather imprecise way, because it is unknown what the project will lead to or whether the formulated theses will be possible to verify” (biology, computer science, robotics, economy, archaeology, psychology);
- “Some research projects remind a wild goose chase and their goal are extremely uncertain” (biology, robotics);
- “It is common practice to have ready results before applying for a project, otherwise there would be a too high uncertainty as to the attainability of the goals which have to be stated precisely in the application forms” (economy);
- “In R&D projects we verify a theoretical model in order to construct a fully new solution in practice, thus the uncertainty is high” (economy);
- “R&D project goals cannot be formulated very precisely, because their attainment is achieved iteratively” (management);
- “In humanities, it is impossible to foresee project outcomes in a precise way. A negative answer is also a valuable answer. In my project we formulated the goals with the lowest possible detail degree” (linguistics, philosophy);
- “The achievement of project goals in R&D projects depends strongly on hypotheses verification” (physics);

- “Research projects should only indicate new research directions and not necessarily lead to concrete products” (physics);
- “In the imposed project duration (maximal 5 years) it is possible only to attain a very rough objective, to lay a foundation for further research, which should take 10–15 years” (archaeology).

We can thus see that in the phase of R&D project definition in numerous cases a lot of well justified uncertainty exists. And it has to be underlined that financing institutions which finance a substantial part of university-based projects require a great deal of certainty/detail while applying for funding. Let us use as an example the Polish National Science Centre, whose form for project application is as follows:

Table 3. Research project application form (National Science Center, <https://www.ncn.gov.pl/?language=en>)

Form element notation	Form element name	Form element description
RPO	Research Project Objectives	Research problem aimed to be solved by the applicant, project’s research hypotheses
SP	Significance of the project	State of the art, justification for tackling specific scientific problems by the proposed project, pioneering nature of the project, the impact of the project results on the development of the research field, and scientific discipline
WP	Work plan	Outline of the work plan, critical paths, state of preliminary and initial research indicating the feasibility of research objectives
RM	Research Methodology	Underlying scientific methodology, data reduction and treatment schemes, type and degree of access to the equipment to be used in the proposed research

The information required in the form presented in Table 3 is fairly precise, all the elements SP, WP and RM require an exact formulation of the project goals (objectives). As the above considerations, presented in this and in the previous section indicate, such a formulation of the project objectives is often not possible in R&D projects.

In many projects, it is unknown which objective will be ultimately pursued (e.g. in archaeological projects) and which methods will be used. Requiring that applicants declare clearly the objectives and the methods and tasks constitute in many cases an obstacle to innovativeness. In the above cited research, some interviewees told us they do not apply to funding agencies because they know that with the imposed maximal project duration (usually 3–5 years) they are not able to achieve with a reasonable probability any goal in a way that would be accepted by these agencies.

A possibility to solve this problem would be to persuade research funding agencies to introduce new, more flexible formats to use in the project application. One proposal would be to allow the format of an agile project definition (Kuchta, 2014, Kuchta & Skowron, 2017). Another proposal would be to allow (and at the same time to force) the applicants to indicate explicitly the uncertainty degree of each element of the proposal, thus of the elements of Table 3. Here we would like to propose to use in project definition fuzzy sets. Their idea will be described in the next section.

### 3. Type 1 and 2 fuzzy numbers – basic information

Fuzzy sets, introduced by Zadeh (1965), are meant to express preferences or uncertainty. Here their latter usage will be considered: uncertainty modelling and measurement.

**Definition 1:** A type 1 fuzzy set  $\tilde{A}$  is a couple  $(Z_A, \mu_A)$ , where  $Z_A$  is a set of objects and  $\mu_A$  is a function (called membership function) defined on  $Z_A$  with values in the interval  $[0,1]$ . Value  $\mu_A(z)$  for  $z \in Z_A$  can be interpreted in various ways, among others as the possibility of the occurrence of  $z$ . The higher  $\mu_A(z)$ , the higher the possibility that element  $z \in Z_A$  will occur. Values  $\mu_A(z)$  are given by experts.

A special case of type 1 fuzzy sets are fuzzy numbers. The following simplified definition will be assumed here:

**Definition 2:** A fuzzy number is a type 1 fuzzy set where  $\tilde{A}$  where  $Z_A = \mathcal{R}$  (where  $\mathcal{R}$  stands for the set of real numbers) and  $\mu_A$  is a continuous function (see Figure 1).

Usually, special types of fuzzy numbers are considered, especially triangular fuzzy numbers. In case of triangular fuzzy numbers the membership function has a triangular shape.

A triangular fuzzy number can be defined as a triple  $(a_1, a_2, a_3)$ , where  $a_1, a_2, a_3$  are such real numbers that  $a_1 < a_2 < a_3$ . Such a fuzzy number represents a quantity which – according to the knowledge or belief of the decision maker in the very moment – will take on the value  $a_2$  with the possibility degree 1, values smaller than or equal  $a_1$  and greater than or equal  $a_3$  with the possibility degree 0, and the other values with the possibility degree between 0 and 1 – the smaller the possibility degree, the greater the distance from  $a_2$ . This can be represented by the following figure:

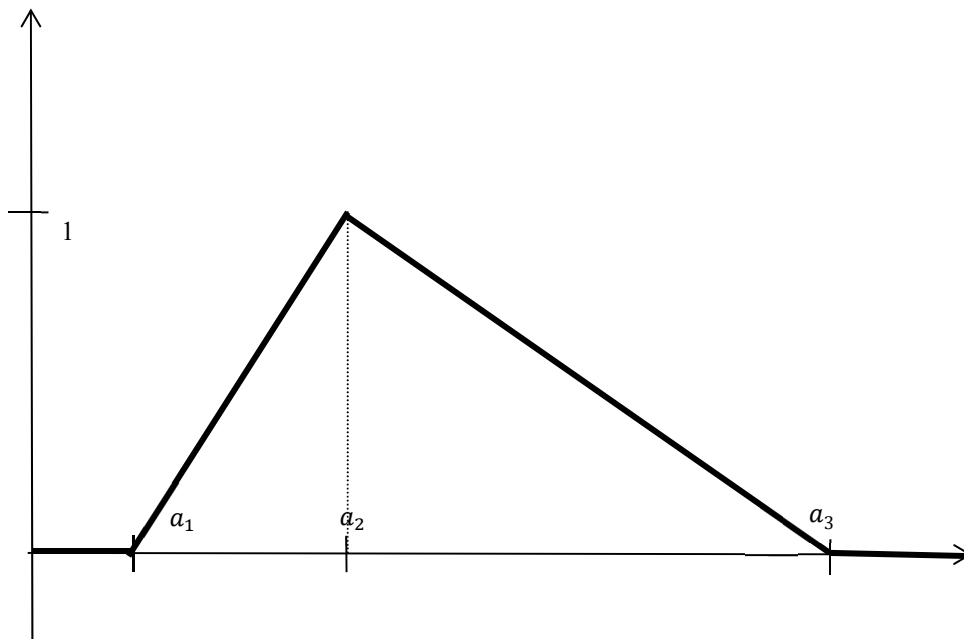


Figure 1. A triangular fuzzy number  $\tilde{A} = (a_1, a_2, a_3)$  and its membership function

Type 1 fuzzy sets, although they are widely used in decision modelling and management, have proven to be insufficient in some cases, for example when experts do not agree on the values of  $\mu_A$ . That is why type 2 fuzzy sets were introduced, which are a generalisation of type 1 fuzzy sets (Mendel & John, 2014, Mendel, 2015).

**Definition 3:** A type 2 fuzzy set  $\tilde{A}^2$  is a couple  $(Z_A, \tilde{\mu}_A)$ , where  $Z_A$  is a set of objects and  $\tilde{\mu}_A$  is a function defined on  $Z_A$  with values in the set F, where F is the set of all fuzzy numbers.

The following example illustrates the difference between type 1 and type 2 fuzzy sets:

**Example 1:** Let  $Z_A$  be the set of four (independent) project objectives:  $Z_A = \{O_1, O_2, O_3, O_4\}$ . A type 1 fuzzy set  $\tilde{A}$  would be couple  $(Z_A, \mu_A)$ , where:  $\mu_A(O_1) = 0.2$ ,  $\mu_A(O_2) = 0.4$ ,  $\mu_A(O_3) = 0.7$ ,  $\mu_A(O_4) = 0.8$ . The values of  $\mu_A$  are given by experts. These values mean that the experts feel that the attainment of  $O_1$  is nearly impossible – the possibility degree is here close to 0, while the attainment of  $O_4$  is held as fairly possible, although not completely possible (the attainment degree is close to 1, but not equal 1).

A type 2 fuzzy set would be used in this case if the experts were not ready to give concrete possibility values or if there were more experts who would not find a crisp consensus and they would prefer to give rough or fuzzy possibility degrees, like “about 0.2”, or in the form of linguistic terms (e.g. “very low”, “low”, “medium”, “high”, “very high”). Both the expressions of type “about 0.2” and the linguistic terms can be modelled by means of fuzzy numbers. Then we would deal with a type 2 fuzzy set  $\tilde{A}^2 = (Z_A, \tilde{\mu}_A)$ , where for example we would have:

$$\tilde{\mu}_A(O_1) = (0.1, 0.2, 0.3), \tilde{\mu}_A(O_2) = (0.1, 0.4, 0.6), \tilde{\mu}_A(O_3) = (0.5, 0.7, 0.9) \text{ and } \tilde{\mu}_A(O_4) = (0.8, 0.9, 1).$$

We can see that in case type 2 fuzzy sets are used the possibility degrees of various objectives overlap each other, because the experts have specified, for each objective, a range of various degrees of attainment possibility with various degrees of truth. For example, for objective  $O_3$  the attainment degree whose truth degree is the highest is 0.7, but it is also possible (according to the experts) that the possibility degree of the attainment of this objective will be higher or lower, within the range [0.5, 0.9].

It has to be underlined that when type 2 fuzzy sets are used, it may be impossible to rank the objectives according to their attainment possibility. This is due to the fact that fuzzy numbers ranking is generally not unequivocal (Hanss, 2010). For example, we cannot say definitely (which was possible in case type 1 fuzzy sets were used) that the attainment possibility of  $O_2$  is lower than that of  $O_3$ . This reflects the complex nature of uncertainty we often face in reality.

## 4. Application of type 1 and type 2 fuzzy sets to R&D project definition

### 4.1. General concept

The general concept we propose would be to allow type 1 and type 2 fuzzy sets to describe various attributes of R&D project goals and tasks. As the above research indicates, uncertainty inherent in R&D projects is so high that in many cases it is impossible to state that a certain goal will be achieved or a task will be performed. We think it is better not to force applicants for R&D research support to create fiction, but rather allow them to apply for clearly uncertain projects, with unknown outcomes or even unknown methods and tasks. In our opinion, it is a unique way to encourage researchers with interesting or even groundbreaking ideas to apply for research support, which would make it possible for them to give a try to their cutting-edge ideas.

Type 1 and type 2 fuzzy sets should be used to describe the elements of Table 3, which is presented in Table 4.

Table 4. Research project application form proposal taking into account uncertainty

Form element notation	$Z_A$	$\mu_A$ or $\tilde{\mu}_A$
RPO	Set of objectives	Possibility degree that individual objectives will be attained (fully), possible fraction of the objectives that will be attained (in case of objectives which probably will be attained only partially)
WP	Tasks to be performed	Possibility degree that individual tasks will be able to be performed (fully), possible fraction of the tasks that will be performed (in case of tasks that can be performed partially)
RM	Methods to be used	Possibility degree that a method will be used in the project

Each fuzzy set used will have to be justified (why the possibility of degrees are less than one). The evaluators deciding about funding a project should evaluate the described fuzzy sets at the background of the innovativeness of the project.

Moreover, as many researchers indicate the interactive nature of R&D projects and the necessity to use agile methods (Holzmüller-Laue & Göde, 2011, Dowling, 2014, Kuchta, et al. 2017), Table 4 will have to be updated systematically during project realisation. At project completion, the evaluators should evaluate whether the outcome obtained corresponds to what was planned, taking into account the uncertainty expressed in the initial Table 4 and in its updates delivered during project realisation.

### 4.2. Case study

We will here use a real world R&D project where the author of the paper held the role of project manager. Only the set of objectives will be discussed here (and not tasks or methods).

The project belonged to the domain of management and regarded the development of a costing system for a Polish university (called here university X) which would serve as a basis for the development of a costing system for other Polish universities. It has to be underlined that costing methods presently used at most universities do not deliver reliable managerial information. The complexity of processes existing today at universities has made the traditional costing methods inadequate. The costing methods which do deliver reliable managerial information are generally very difficult to implement in the university context (Cropper & Cook, 2000).

On the whole, it can be said that the project was almost a failure. In our opinion, this is partially due to the fact that its objectives, tasks and methods had to be described in detail before the project start, although the team writing the proposal had no access to data or to financial services of the university. This access was promised (by the university management) to be granted once the funding is given and the project is started. And it was only once the project started that the actual attitudes of numerous stakeholders and above all the actual state of available data became known.

In Table 5 we present the objectives of the project as they were described in the application for funding.

Objective O1 was achieved only partially: a model was elaborated, but the implementation was rudimentary. This was due to the fact the accounting department and its employees were not interested in the implementation and they did not cooperate. Also, objective O2 was realised only partially, because, due to the resistance of the employees, but also to the lack of order in the existing data, it was impossible to get acquainted with the present university costing system and its nuances or disadvantages. For the same reason, the realisation of objective O3 was limited to theoretical considerations. Objective O4 was hardly achieved at all because the respective information about the organisation of the university was not available. The same can be said about objective O4.

Also, the planned research tasks partially could not be implemented and not all research methods (like interviews, case study) were able to be applied.

Table 5. Research project application form for the case study

Project objective notation	Project objective description
$O_1$	The project will lead to a model of cost calculation for universities and its pilot implementation in a selected area of University X.
$O_2$	The project will lead to a costing system concept which will constitute a direct input to a computer implementation of a professional university costing system.
$O_3$	The project will indicate methods of costing of research and teaching processes at universities – which will deliver information useful for university managers
$O_4$	The project will deliver, for University X, reliable cost of individual students, specialisations, classes, faculties and of other units whose cost should be known to University managers.
$O_5$	The project will lead to a detailed requirement specification for a costing system for Polish universities.

In fact, most of the negative phenomena described above was foreseen in the risk analysis conducted before the project start. However, it was not possible to integrate the risk (or uncertainty) analysis with project objectives. There was no way of indicating to the reviewers of the application that individual project objectives from the very beginning were linked to a high uncertainty (the possibility of attaining the individual objectives would have been estimated in the range [0.2, 0.5]), but that in spite of this it was still important to give it the project a try. It is true that the final outcome of the project can be seen as an almost failure and it is only thanks to the indulgence of the evaluators of the final report that the project was accepted. On the other hand, even if the project can be seen as a failure in the present form of its description (the one with objectives formulated like in Table 5, without any reference to uncertainty), the project manager and the project team do not see it as a complete failure: it allowed us to gain a deeper understanding of university administration mentality and it gave rise to other management projects we applied or are applying for. A project which followed directly from the project described here, for which we were given the funding and which finished with a substantial success, was a project about success factors of R&D projects at universities. It is only having understood these success factors that is possible to implement an innovative R&D project regarding university management with success. Without the almost failed project, we would not have understood that and we would not have applied for the other project, whose success and whose outcomes constitute for us a huge source of new research ideas.

## Conclusions

We propose here a new approach to R&D project definition, which in our opinion should be used in grant application by R&D supporting agencies. R&D activities should open completely new ways and territories and this is not possible without a high level of uncertainty. This uncertainty should be revealed openly in grant applications, should be justified and measured. This truth is supported in the paper by statements of R&D projects managers who often feel a discrepancy between the nature of the projects they should or want to implement and the application forms they have to fill in in order to apply for funding. In numerous cases, this discrepancy leads to frustration, because it makes it more and more difficult to obtain funding for groundbreaking research ideas.

Here we propose the utilisation of fuzzy sets for the description and quantification of uncertainty. Each application for R&D project funding could then be measured with respect to its uncertainty, which should be compared with the originality and innovativeness of the research proposal.

It would be necessary to combine the proposed approach with the iterative or agile approach. It is not in accordance with the nature of R&D projects that the initial proposal is not systematically updated. The updating procedure should also concern the fuzzy evaluations of uncertainty. In most projects, the uncertainty will diminish as the project continues, but in some R&D projects it may increase, according to the rule “the more I know, the less I understand”.

In this paper, one case study was deeper analysed. It is an R&D project in which the initial goals were hardly attained, thus the project final report was on the verge of being rejected. This was due to the high uncertainty inherent in this project, which unfortunately materialised during project implementation. And still the project manager and the project team feel that this project attained other objectives, above all it gave the project team a deeper understanding of certain phenomena. And it is thanks to this deeper understanding that new R&D projects arose and were implemented, this time with success.

Naturally, further research, above all further case studies (similar to Song et al. (2007) and research on uncertainty modelling by means of fuzzy sets in the context of R&D projects are needed in order to elaborate proposals which could be implemented in the practice of R&D projects calls. An important future research direction should be the problem of how to support the researchers in expressing their feeling or opinions about project uncertainty by means of fuzzy sets (Benoit, 2013).

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