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REALISTIC PLANNING OF RESEARCH AND DEVELOPMENT PROJECTS

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Abstract. *Purpose* – the purpose of the article is to propose a more flexible approach to the planning of research and development projects, especially for the needs of project calls. In those calls, financial means are often refused to projects with a high level of uncertainty. The proposal should support a positive assessment of the most pathbreaking projects and a flexible reaction to the failure or partial failure of such projects.

Research methodology – In the proposal type 1 and type 2 fuzzy sets are applied. The proposal will is using case studies.

Findings – the results will modify the way research and development project are planned and controlled.

Research limitations – the proposal has not been verified in practice, for which many more case studies and cooperation with financing institutions would be necessary. Also, it does not use up all the modelling possibilities of uncertainty and dependencies between various uncertain elements of the project plan.

Practical implications – the results might be used in the design of forms used by various financing institutions (e.g. European Commission or national research funding institutions) in project calls.

Originality/Value – the proposal presents an entirely different way research and development projects should be planned and described. Type 2 fuzzy sets are used for the description, where various elements of the project plan (e.g. objectives, methods, tasks) are assigned a possibility degree (of attainment, of usage etc.)

Keywords: research project, R&D project, project plan, project uncertainty, fuzzy set.

JEL Classification: O31, O32.

Introduction

The subject of this paper are R&D (research and development) projects, which will be understood here as either research projects (i.e. projects undertaken with the objective of acquiring or generating new knowledge) or research and development projects (projects which

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use the existing knowledge in order to create new products or processes (Klaus-Rosińska, 2019)). R&D projects 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 right and try to construct machines with functionalities of which we do not whether they are able to be achieved.

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 precisely according to the imposed format. This format requires them to specify, among others, the research objectives, methods and research tasks. However, these elements are often not wholly known or cannot be described precisely before the project is started (which is explicitly shown, e.g. in Shenhar (2001) or Kuchta and Skowron (2016)). As shown, e.g. in Kuchta et al. (2017a), in numerous research projects, especially the most innovative and path-breaking ones, only few elements can be regarded as known. 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 satisfied, 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 at the moment when the results are already known, or 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.

Thus the aim of this paper is to propose another approach, in our opinion a more realistic one, to R&D project planning, to be used mainly, but not exclusively in application forms in various R&D project calls. This approach should allow planning each R$D project, even a highly path-breaking one, in a manner fulfilling the following conditions:

- The researcher will be able to present his or her actual knowledge about the project without the risk to be punished by reviewers for an incomplete or too general project description;
- The financing institution will be able to finance the project dynamically and flexibly, depending on the continuous reporting of the results;
- Such (today popular (Kuchta et al. 2017a)) phenomena as financing of R&D projects which have lost their "raison d'être", straining the project description to the formal requirements, distorting project results in order to fit the original project goal, refusal to finance highly innovative, path-breaking projects characterized by a high uncertainty and lack of knowledge will be substantially reduced.

We will attempt to reach this objective through the use of a formal tool called type 1 and type 2 fuzzy sets. They are helpful in case of uncertainty and lack of knowledge. Being a mathematical notion, they can be used in a more user-friendly form – in that of linguistic expressions, borrowed from human language.

The structure of the paper is as follows: In Section 1 we review the state of art of the existing research on uncertainty in R&D projects. In Section 2 we describe the results of our recent research where researchers expressed their opinion about the high uncertainty inherent in their projects, and we present an example of a real-world application form. In Section 3 we describe type 1 and type 2 fuzzy numbers and their linguistic-based versions. Then, in Section 4.1, we propose a change in the application forms for R&D project calls, consisting mainly of introducing a unique structure for the description of research objectives and tasks. In Section 4.2 we illustrate the problem and the proposed approach utilising two real-world case studies. We close our paper with some conclusions.

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

So-called traditional project management (Project Management Institute, 2018; Wysocki, Kaikini, & Sneed, 2014) sets that projects should be defined according to specific rules. For example, the project goals should be described respecting the SMART principle: they should be Specific, Measurable, Attainable, Realistic and Time-related. These principles have proven to be useful, 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), inevitably, 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, methods and materials needed to build a bridge can be estimated within precise tolerances, but fairly precisely (if we deal with considerable delays in construction projects, they are usually due instead 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 complicated. 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 somewhat 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 sharply 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 merely 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 for the project goal and the methods to achieve it. Shenhar (2001) and Kuchta and Skowron (2015) has introduced the following project classification:

Table 1. Project classification (Kuchta & Skowron, 2016)

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

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. The especially high value of a 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 exactly in the phase of applying for financing.

Even if we assume that the project goal can be defined or that its certain equivocality or fuzziness is accepted, we have another problem on the level of research tasks. As it is described by Kuchta (2014), in R&D projects, there may exist a high level of non-determinability of research tasks. Like the case of one prominent car manufacturer shows (Courtot, 1998), in the moment of R&D project planning the following elements may be not fully known:

- The list of tasks that will be executed (there may exist a list of potential tasks, but it may be unknown which ones will be executed or not). For example, there may be several tests, out of which only one will be performed, depending on a future result.
- The content of individual tasks (i.e. what the task will actually consist in – this may follow only from other tasks). For example, a test may use various methods, depending on the result of another test.

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

– The competences needed for the execution of a task (this may follow from the exact task content, which will be known only in the future);
– The duration of the task (it may depend on various factors, but especially firmly on the content);
– The number of times the task will be repeated (this may depend on the results of the task performance). For example, an experiment may be repeated as many times as it is necessary to verify or rejects a hypothesis.

Kuchta (2014) proposed a new description form for R&D tasks, in which the above lack of knowledge is clearly expressed. This form will be used in the following, but here fuzzy numbers will be applied (the description proposed in (Kuchta, 2014) is purely linguistic).

Holzmüller-Laue and Göde (2011), Dowling (2014), Kuchta et al. (2017a), Solak, Clarke, Johnson, and Barnes (2010), and Song, D.-H. Lee, Y.-G. Lee, and Chung (2007) point out to other uncertainty sources in R&D projects, which support the thesis that the uncertainty in R&D projects may be substantial.

2. Uncertainty in R&D projects – research results

Within a research project (the project manager was the author of this paper) 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 experiments' results" (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. Moreover, 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:

The information required in the form presented in Table 3 is relatively precise; all the elements SP, WP and RM require an exact formulation of the project goals (objectives). On top of that, WP is based on an exact list of tasks to be performed, together with the necessary human and financial resources. RM needs the knowledge of all the methods which will be used in the project implementation. As the above considerations, presented in this and the previous section indicate, such a description is often not possible in R&D projects.

In many R&D 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 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 project applications. One proposal would be

Table 3. Research project application form (National Science Center)

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, the 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

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 and sets – 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 $(\boldsymbol{Z_A}, \mu_A)$, where $\boldsymbol{Z_A}$ is a set of objects and μ_A is a function (called *membership function*) defined on $\boldsymbol{Z_A}$ with values in the interval [0,1]. Value $\mu_A(z)$ for $z \in \boldsymbol{Z_A}$ 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 $z \in \boldsymbol{Z}_A$ will occur. Values $\mu_A(z)$ are given by experts. The core of a fuzzy set $(\boldsymbol{Z_A}, \mu_A)$ will be the element(s) of $\boldsymbol{Z_A}$ with the highest membership function value. It will be denoted as $Cor(\tilde{A})$.

$Cor(\tilde{A})$ may be one element or a set of more elements. When it is obvious that it is one element, the symbol $Cor(\tilde{A})$ will be used as a number, in other cases as a set.

A special case of type 1 fuzzy sets is 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 $Z_A \subseteq \mathcal{R}$ (where $\mathcal{R}$ stands for the set of real numbers).

In case of fuzzy numbers μ_A may be a continuous function. 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 1.

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 μ_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 (Kuchta, 2019a): *A type 2 fuzzy set* $\widetilde{A^2}$ is a couple $(\boldsymbol{Z_A}, \tilde{\mu}_A)$, where $\boldsymbol{Z_A}$ is a set of objects and $\tilde{\mu}_A$ is a function defined on $\boldsymbol{Z_A}$ with values in the set $\mathcal{F}$, where $\mathcal{F}$ is the set of all fuzzy numbers.

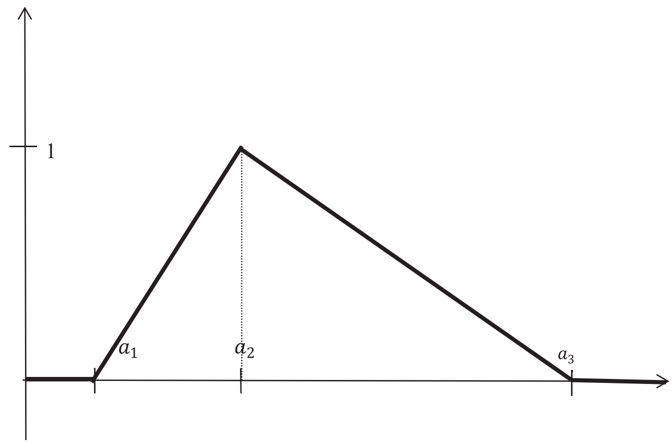

Figure 1. A triangular fuzzy number and its membership function

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

Example 1: Let Z_A be the set of four (independent) project objectives: $\boldsymbol{Z_A} = \{O_1, O_2, O_3, O_4\}$. A type 1 fuzzy set $\tilde{A}$ would be the couple $(\boldsymbol{Z_A}, \mu_A)$, where μ_A would model the degree to which, according to the experts, the attainment of the corresponding project objective is possible: $\mu_A(O_1) = 0{,}2$, $\mu_A(O_2) = 0{,}4$, $\mu_A(O_3) = 0{,}7$, $\mu_A(O_4) = 0{,}8$. The values of μ_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". Then we would deal with a type 2 fuzzy set $\widetilde{A^2} = (\boldsymbol{Z_A}, \tilde{\mu}_A)$, where for example we would have: $\tilde{\mu}_A(O_1) = (0{,}1, 0{,}2, 0{,}3)$, $\tilde{\mu}_A(O_2) = (0{,}1, 0{,}4, 0{,}6)$, $\tilde{\mu}_A(O_3) = (0{,}5, 0{,}7, 0{,}9)$ 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 possible 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 he 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.

Here we will use a special type of type 2 fuzzy sets, with possibility degrees being so-called fuzzy possibility degrees.

Definition 4: A type 1 fuzzy number $\tilde{A}$ will be called a fuzzy possibility degree iff $\boldsymbol{Z_A} \subseteq [0,1]$.

In the following example, we present selected examples of fuzzy possibility degrees, based on Korol (2012).

Example 2: Let us consider the following fuzzy possibility degrees (their membership functions are presented in Figure 2):

VL = (0, 0, 0.25) – very low

L = (0, 0.25, 0.5) – low

M = (0.25, 0.5, 0.75) – middle

H = (0.5, 0.75, 1) – high

VH = (0.75, 1, 1) – very high.

The fuzzy possibility degrees "very small", "small", "medium", "high" and "very high" presented in Figure 2 represent notions which are not crisp in human understanding. We can see here the overlapping mentioned above: value 0.875 is considered to be both high and very high to the degree 0.5.

The fuzzy possibility degrees will be applied to the definition of the special type 2 fuzzy sets that will be used in the following part of the paper:

Definition 5: A type 2 linguistic fuzzy set $\widetilde{A^2}$ is a couple $\left(\boldsymbol{Z_A}, \tilde{\mu}_A\right)$, where $\boldsymbol{Z_A}$ is a set of objects and $\tilde{\mu}_A$ is a function defined on $\boldsymbol{Z_A}$ with values being fuzzy possibility degrees.

Example 3: Let us return to Example 1 and Example 2. A type 2 linguistic fuzzy set would be the set of objectives $Z_A = \{O_1, O_2, O_3, O_4\}$ with attainment possibilities as follows: $\tilde{\mu}_A(O_1) = \text{small}$, $\tilde{\mu}_A(O_2) = \text{high}$, $\tilde{\mu}_A(O_3) = \text{very small}$ and $\tilde{\mu}_A(O_4) = \text{very high}$.

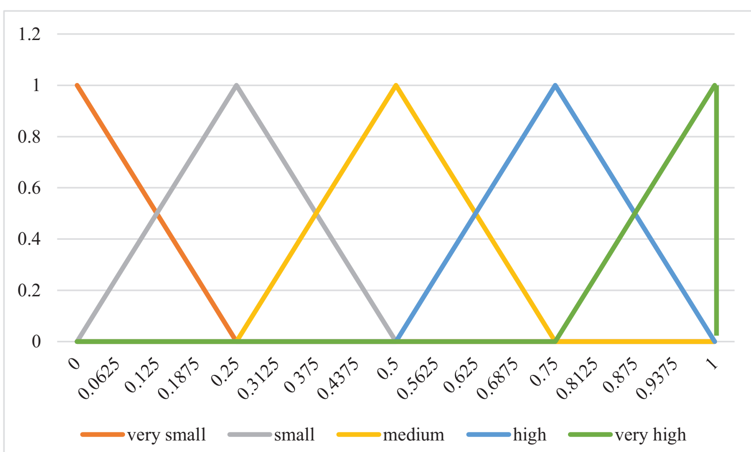

Figure 2. Examples of fuzzy possibility degrees

Fuzzy numbers can be manipulated like crisp numbers: they can be among others added to each other und multiplied with a crisp number (Zadeh, 1965). We will use here the following definitions:

Definition 6: Let $(\boldsymbol{Z_A}, \mu_A)$ and $(\boldsymbol{Z_B}, \mu_B)$ be two type 1 fuzzy numbers and s a crisp nonnegative number. Then (Zadeh, 1965) we define:

a) $s \otimes (\boldsymbol{Z_A}, \mu_A) = (s\boldsymbol{Z_A}, \mu_{sA})$, where $s\boldsymbol{Z_A} = \{x : \exists z \text{ such that } x = sz \text{ and } z \in \boldsymbol{Z_A}\}$ and $\mu_{sA}(sz) = \mu_A(z)$;

b) $(\boldsymbol{Z_A}, \mu_A) \oplus (\boldsymbol{Z_B}, \mu_B)$ will be defined as such $(\boldsymbol{Z_C}, \mu_C)$ that $\boldsymbol{Z_C} = \boldsymbol{Z_A} + \boldsymbol{Z_B}$ (i.e. $\{x : \exists y, z, y \in \boldsymbol{Z_A}, z \in \boldsymbol{Z_B}, x = y + z\}$) and $\mu_C(x) = \max_{y,z:x=y+z} \min(\mu_A(y), \mu_B(z))$.

Example 4: Let us consider two fuzzy numbers $(\boldsymbol{Z_A}, \mu_A)$ and $(\boldsymbol{Z_B}, \mu_B)$, $\boldsymbol{Z}_A = \{3,4\}, Z_B = \{1,2\}$, the corresponding possibility values being (for $\boldsymbol{Z_A}$) 0,2 and 0,3 and (for $\boldsymbol{Z_B}$) 0,1 and 0,4. Then

a) $3 \otimes (\boldsymbol{Z_A}, \mu_A) = (\boldsymbol{Z_C}, \mu_C)$, where $\boldsymbol{Z_C}$ is composed of elements 9 (with the possibility degree 0,2) and 12 (with the possibility degree 0,3):

b) $(\boldsymbol{Z_A}, \mu_A) \oplus (\boldsymbol{Z_B}, \mu_B) = (\boldsymbol{Z_C}, \mu_C)$, where $\boldsymbol{Z_C}$ is composed of the elements 4 (with the possibility degree 0.1), 5 (with the possibility degree 0.2) and 6 (with the possibility degree 0.3).

Let us now pass on to the main proposal of this paper.

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

4.1. General concept

The general concept we propose (sketched by Kuchta, 2019b) 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, the uncertainty inherent in R&D projects is so high that in many cases it is impossible to state that a specific goal will be achieved or a task will be performed and how. We think it is better not to force applicants for R&D research support to create fiction, but it would be better to 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 exciting 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, especially linguistic type 2 fuzzy sets, should be used to describe the elements of Table 3. Here we will assume linguistic type 2 fuzzy sets, but the other types of fuzzy sets would also be possible.

The first requirement is that the financing of R&D projects will not be definitely decided in the moment of project application. The financing decision for R&D projects should be stepwise, taken only preliminarily at the beginning and adjusted in the course of project execution (this includes the possibility of breaking the project). Thus, the financing institution should define, for each project P, moments in time $t = t_1^P (= 0)$, … t_j^P, …, t_T^P, where t= $t_1^P = 0$ is the moment of project application and t_T^P is a moment where no more changes in the project financing will be possible, in which project budget will be reconsidered. $\mathcal{B}_t^P$ will stand for the financial resources assigned to project P in the moment t.

The project forms at the moment $t = 0$ should contain the following elements (apart from the (obviously always required) text description *SP*):

– *RPO* – set of projects objectives, expressed preferably as a linguistic type 2 fuzzy set $\left(\boldsymbol{Z_P}, \tilde{\mu}_P\right)$, where $\boldsymbol{Z_P}$ is the set of potential objectives of the project in question (denoted as *P*) ($\boldsymbol{Z_P} = \left\{O_1^P, \ldots, O_i^P, \ldots, O_{N_P}^P\right\}$) and $\tilde{\mu}_P$ expresses in linguistic terms the possibility (assessed in moment $t = 0$, being the moment of presenting the project application) of the objective attainment;

– *WP* – composed of the set $\boldsymbol{T_P} = \left\{T_1^P, \ldots, T_i^P, \ldots, T_{M_P}^P\right\}$ of potential project tasks, given as a linguistic type 2 fuzzy set $\left(\boldsymbol{T_P}, \tilde{\mu}_{TP}\right)$, where $\tilde{\mu}_{TP}$ represents in linguistic terms the possibility degree (assessed in moment $t = 0$) that the respective task will be performed and for each task T_i^P, $i = 1, \ldots, M_P$, the following linguistic type 2 fuzzy sets:

  - $\left(\boldsymbol{C_i^P}, \tilde{\mu}_{DP}^i\right)$, where $\boldsymbol{C_i^P} = \left\{C_{i,1}^P, \ldots, C_{i,j}^P, \ldots, C_{i,MC_{i,P}}^P\right\}$ is the set of possible con tents (expressed as text passages) of the respective tasks and $\tilde{\mu}_{CP}^i$ expresses (in linguistic terms) the possibility degree (assessed in moment $t = 0$) that the task will have the respective content.
  - $\left(\boldsymbol{D_i^P}, \tilde{\mu}_{DP}^i\right)$, where $\boldsymbol{D_i^P} = \left\{\tilde{D}_{i,1}^P, \ldots, \tilde{D}_{i,j}^P, \ldots, \tilde{D}_{i,MD_{i,P}}^P\right\}$ is the set of possible times (expressed as fuzzy numbers) needed to perform the respective tasks and $\tilde{\mu}_{DP}^i$ expresses (in linguistic terms) the possibility degree (assessed in moment $t = 0$) that the task takes the respective time. Here, like in the next item, the objects for which a fuzzy possibility degree is defined are fuzzy numbers;
  - $\left(\boldsymbol{B_i^P}, \tilde{\mu}_{BP}^i\right)$, where $\boldsymbol{B_i^P} = \left\{\tilde{B}_{i,1}^P, \ldots, \tilde{B}_{i,j}^P, \ldots, \tilde{B}_{i,MB_{i,P}}^P\right\}$ is the set of possible financial resources quantities needed to perform the respective tasks, expressed as fuzzy numbers and $\tilde{\mu}_{BP}^i$ expresses (in linguistic terms) the possibility degree (assessed in moment $t = 0$) that the task cost will be equal to the very value;
  - $\left(\boldsymbol{R_i^P}, \tilde{\mu}_{RP}^i\right)$, where $\boldsymbol{R_i^P} = \left\{R_{i,1}^P, \ldots, R_{i,j}^P, \ldots, R_{i,MR_{i,P}}^P\right\}$ is the set of possible teams that will be needed to perform the respective tasks and $\tilde{\mu}_{BP}^i$ express (in linguistic terms) the possibility degree (assessed in moment $t = 0$) that the task in question will need the very team;
  - $\left(\boldsymbol{M_i^P}, \tilde{\mu}_{MP}^i\right)$, where $\boldsymbol{M_i^P} = \left\{M_{i,1}^P, \ldots, M_{i,j}^P, \ldots, M_{i,MM_{i,P}}^P\right\}$ is the set of possible methods that will be needed to perform the respective tasks and $\tilde{\mu}_{BP}^i$ express (in linguistic terms) the possibility degree (assessed in moment $t = 0$) that the task in question will need the respective methods;
  - The estimated moment of task start expressed as an interval $\left(t_j^P, t_{j+1}^P\right), j = 1, \ldots, T-1$.

The dependencies between the sets $\left(\boldsymbol{C_i^P}, \tilde{\mu}_{DP}^i\right)$, $\left(\boldsymbol{D_i^P}, \tilde{\mu}_{DP}^i\right)$,$\left(\boldsymbol{B_i^P}, \tilde{\mu}_{BP}^i\right)$, $\left(\boldsymbol{R_i^P}, \tilde{\mu}_{RP}^i\right)$, $\left(\boldsymbol{M_i^P}, \tilde{\mu}_{MP}^i\right)$ should be explained as far as known. Typically, the task financial needs are a function of task content, duration, project resources and methods used; also the project duration may be a function of the other elements.

The decision (in moment $t = 0$) whether the project should be accepted for financing should be made mainly based on the attractiveness of the objectives $Z_P = \left\{O_1^P, \ldots, O_i^P, \ldots, O_{N_P}^P\right\}$, independently of their attainment possibilities (in order not to block projects with highly attractive, but somewhat risky – in terms of attainment – objectives) and on the estimated budget of project P. The budget in moment $t = 0$ will be highly imprecise, because of the numerous uncertainties, but its average value can be approximated, for example as follows:

Definition 7: Let us use Definition 6.

a) For the i-th task we calculate an estimation of the needed budget as $\tilde{B}_P(i) = \sum_{j=1}^{MB_{i,P}} \tilde{B}_{i,j}^P \oplus Cor\left(\tilde{\mu}_{BP}^i\left(\tilde{B}_{i,j}^P\right)\right)$. $\tilde{B}(i)$ would be a fuzzy number;

b) For the whole project estimation of the needed budget $\tilde{B}_P$ would be another fuzzy number, defined in the following way: $\tilde{B}_P = \sum_{i=1}^{M_P} \tilde{B}_P(i) \otimes Cor\left(\tilde{\mu}_{TP}\left(T_1^P\right)\right)$.

However, the actual transfer of fonds should regard only those tasks for which the projected starting time is in the interval $\left(t_1^P, t_2^P\right)$. The concrete amounts can be negotiated, in case of doubts it may me equal to $max\left\{x : x \in Cor\left(\tilde{B}_P(i)\right)\right\}$.

Before each moment t_j^P the information listed above has to be updated and another transfer, for the tasks to be started in the following interval $\left(t_j^P, t_{j+1}^P\right)$, corrected by the information of the financial means remaining form the hitherto project execution, should be transferred.

If in any moment the project manager feels the most attractive project goals cannot be attained, a breakup of the project should be considered, in order to free the financial means for other potentially attractive projects.

4.2. Case studies

We will here use two real-world R&D projects where the author of the paper held the role of project manager.

The first 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 partial since 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 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. Furthermore, 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 4 we present the objectives of the project as they were described in the application for funding.

Table 4. Research project application form for the case study

Project objective	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 cost of research and teaching processes at universities – which will deliver information useful for university managers
O_4	The project will deliver, for University X, true 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.

Objective O_1 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 O_2 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 the objective O_3 was limited to theoretical considerations. Objective O_4 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 O_5.

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

Most of the negative phenomena described above were 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, to indicate to the reviewers of the application that individual project objectives from the 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 despite this it was still essential 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 4, 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 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.

Here we will present (*post factum*, attempting to recall the state of our knowledge from the moment before the projects start), the application form we think it would have been desirable to have in reality, in order to prepare a realistic project plan and to optimise the financial resources usage at the background of project objectives.

Table 5. Proposed *RPO* for the case study in the form of a linguistic type 2 fuzzy set

Project task	Possibility degree of attainment	Justification
O_1	high	The project team has the knowledge of numerous costing models and is composed of persons employed at the university in question, who will have access to the necessary data.
O_2	middle	The team may have limited access to other universities and may thus have too little knowledge to create a general concept.
O_3	high	The project team is knowledgeable about various costing methods.
O_4	high	The project team will have access to the data from their university and has the necessary knowledge of their university functioning.
O_5	middle	Like for O_2

As can be seen from Table 5, we were aware of the fact that some objectives were not very probable to be attained. Furthermore, still, they were in our opinion attractive from the point of view of the theory and practice of university cost management, especially those whose attainment was assessed as low. Thus, we think it was necessary to attempt to implement the project, even if today we know that this attempt was not successful.

Let us now pass to the project tasks. Below we present their original list, from the project application form. In that form, the tasks names together with the number and scientific title of the required resources, the quantity of required financial resources and the realisation starting and ending moment had to be given.

Table 6. The original list for the case study project tasks

Project task	Description
T_1	Preparation phase, identification of necessary data and contact persons.
T_2	Analysis of the functioning of the University, of its organisational structure, of the current costing system. Definition of potential data sources.
T_3	Elaboration of the model concept, definition of basic model elements, including cost object structure, processes/activities to be costed, cost drivers, resources drivers, variability drivers. Construction of a conceptual model of cost flow. Validation of the assumed concept.
T_4	Analysis of the computer environment. Analysis of the current state of the computerisation of Polish universities. Definition of requirements concerning the computer environment. Review of the existing software fulfilling the defined requirements. Recommendations and a development plan for a university computer environment in the context of cost management.
$_T5$	Implementation of the elaborated model on the example of one area of the University. Selection of the area and preparation of the implementation. Adaptation of the model to the selected area. Implementation in a selected computer environment.

In our opinion these tasks should have been described more thoroughly, using the proposal from Section 4.1. Let us illustrate the idea of this approach, not recurring to the formalism defined in Section 4.1. Let us start with the task T_3 from Table 6.

- Task content: the content of the task might have been a simple model (possibility degree small), a fairly difficult model (possibility degree high) and a very complicated model, too complicated for the project team to accomplish (possibility degree very low);
- Methods used: for a simple and a fairly complicated model basic text editing systems would have been sufficient, for a very complicated model computer-aided design software would have been necessary;
- Resources needed: for the complicated system special computer and design competences would have been needed.

Let us now consider task T_4 from Table 6. This task might have a content easy to manage for the project team (possibility degree very small), possible to manage for the project team (possibility degree very high) and impossible to manage for the project team (possibility degree small). According to the option, less or more persons would have to be involved, and less or more direct visits at other universities or online contacts would have been necessary,

As for project task T_5, in the moment of application for project funds, several content scenarios were possible, with various possibility degrees. The selected area might have been a department, a faculty or a smaller team, each of them representing various disciplines and thus requiring various competences. The highest possible degree would have been assigned to the departments represented by the members of the project team.

It has to be underlined that with the project implementation our initial views on the project objectives and task were changing profoundly. We saw that many assumptions were not fulfilled, many university units and data sources were not available and that each time to most complicated version was the true one. Thus, already 2–3 months after the project start we would have been happy to limit the project and its financing and transfer the financial and human resources to other projects. Unfortunately, because of the rigid system of project financing we had to continue the project whose most attractive objectives had turned out to be practically unattainable.

The second project's basic objective was to find the way the researchers define research and development project success and to identify the main R&D projects success factors. Here, in the moment of preparing the project application, the uncertainty consisted mainly in:

- Not knowing how many researchers would consent to participate wholeheartedly in the interviews and/or questionnaires;
- Not knowing which length of interviews and questionnaires would be acceptable;
- Not knowing whether the best – according to our opinion – research method for the project, workshops simulating and assessing the course of a real project would be able to apply at least once (it was not);
- Not knowing whether it would be possible to differentiate the research tools depending on project and research organisation types.

It has to be underlined that initial promises and declarations from many potential research participants in many cases turned out to be vain or the responses were given without the necessary reflection. The reason was usually the lack of time, of conviction that the project makes sense or of understanding of management approach to projects. All this was becoming clear during the project course, and a more flexible financing and control system would have allowed limiting the cost of the project without deteriorating the main results.

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 entirely 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 challenging 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 for its uncertainty, which should be compared with the originality and innovativeness of the research proposal. Fuzzy sets, both those of type 1 and type 2, might be helpful to attain this objective.

It would be necessary to combine the proposed approach with the iterative or agile approach (Kuchta, L'Ebraly, & Marchwicka, 2017b). It is not following 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, two case studies were deeper analysed. They were R&D projects in which the initial goals were hardly or weakly attained – in one of the projects the final project 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. Moreover, 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. Furthermore, it is thanks to this deeper understanding that new R&D projects arose and were implemented, this time with success. However, we feel that it would have been more advantageous to be more flexible and limit the projects, which would have allowed assigning financial means to other exciting projects.

Naturally, further research, above all further case studies and research on uncertainty modelling employing 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. Notably, the proposal presented in this paper has to be added more structure. Dependencies between individual type 2 fuzzy sets used in the project description, mentioned in the present paper, are usually very strong, and they should be modelled formally, using a kind of networks. They still need to be designed. Also, depending on the project, there may be many more elements that have to be taken into account in the project description (e.g. the number of task repetitions, the learning and experience factor, the problem of competences description and assessment, etc.). Type 1 and type 2 fuzzy sets also have their extensive theory (including the ranking and comparing procedures, the operations of average, similarity) etc, which could also be used, remembering at the same time that the resulting system should not be too formal, as it has to be used in the practice of calls for research and development projects.

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