M U L T I P L E   C R I T E R I A   D E C I S I O N   M A K I N G
Vol. 14 2019

Dorota Kuchta[*]

MULTICRITERIA FUZZY EVALUATION OF PROJECT SUCCESS IN R&D PROJECTS

DOI: 10.22367/mcdm.2019.14.03

Abstract

The paper reviews the state of art in project success evaluation, especially with respect to R&D projects, with emphasis on the ambiguity of such evaluation, its strong dependence on the con-text and on the evaluator. We also recall basic information about fuzzy numbers and propose the concept of fuzzy rules which are used in the suggested procedure of R&D project evaluation. The procedure is described and illustrated by means of a real--world case study.

Keywords: project success, research and development project, fuzzy success evaluation.

1 Introduction

Project success is a notion which is not always unequivocal. It depends strongly on the context and on the evaluator. This phenomenon is especially striking as regards research and development projects. Is an archaeology project, which revealed approximate chances of interesting excavations, successful or not? Or a medical project, in which the medication investigated turned out to be inefficient, but another substance was found which might be efficient, but this can be checked only by conducting another project? Or a project which showed that the assumed procedure is incorrect? Or another one, whose objectives were not attained, but which opened prospects for many new research projects? Or a project which was deemed as being exactly within budget and time, which led to a required number of publications which, however, were written with the full awareness on the part of the authors that the results presented in them are not really valuable?

[*] Wrocław University of Science and Technology, Wrocław, Poland, Dorota.kuchta@pwr.edu.pl, ORCID: 0000-0002-9747-0759.

The author's experience as research and development project manager, as well as the results of a research project (directed by the author) in which R&D projects were examined, show that it is necessary to be very prudent when evaluating R&D projects. First, a variety of criteria has to be used, many of which would not be used in case of e.g. engineering or IT projects. Second, we have to be aware that the evaluation of the success of an R&D project may differ strongly depending on the evaluator and the context. Third, an important issue are soft limits between evaluation grades: it is difficult to say definitely where a research project ceases to be very successful and begins to be only successful.

The objective of this paper is thus to propose a procedure scheme for the evaluation of R&D projects which take into account the issues listed above. The proposed procedure will use the notion of fuzzy sets and fuzzy rules, which help to model soft notions, ambiguity and subjectivity. The proposed procedure will be illustrated with a real-world example.

The content of the consecutive sections is as follows: In section 2 the notion of project success is discussed, for projects in general. In Section 3 this notion is discussed in the context of R&D projects. In section 4 fuzzy sets and fuzzy rules are briefly presented, using an example from the banking sector, as examples from the field of R&D project evaluation are not available. In section 5 the proposed evaluation scheme for R&D projects is described. The paper terminates with conclusions.

2 Project success

Project success (to begin, we will consider any projects, not only R&D projects) is defined in the literature in many different ways. Many authors suggest that a project is successful if it meets the specification (scope), cost (budget) and time (deadline). This is viewed as the most basic level of project success (Greer, 1999), although many authors (e.g. Cheng et al., 2012) use only time and budget as project success measures. However, numerous authors (e.g. Ashley et al., 1987; Baccarini 1999; Baker et al., 1988; Belassi and Tukel, 1996; Camilleri, 2011; Chan and Chan, 2004; Kerzner, 1992; Lim and Mohamed, 1999; Mir and Pinnington, 2013; Pinto and Slevin, 1988; Raz et al., 2002; Thomsett, 2002; Turner, 1994; Wateridge,1998; de Wit, 1988) expand this definition substantially, introducing other project success measures (or, which for us will be synonymous, success criteria).

First of all, the additions to the list of success criteria are a consequence of the following, by now already accepted, opinion: "There have to be two groups of project success measures: objective measures (such as time or cost) and subjective measures (such as the satisfaction of different project stakeholders)" (Chan and Chan, 2004). Subjective measures are necessary, because the perception of project success depends strongly on the assessor (e.g. Davis, 2014). On top of that, other contexts are taken into account, for example (Khan et al., 2013, Freeman and Beale, 1992): organisational benefits, project influence, future prospects gained thanks to the project, technical parameters of the project product, personal development and business profits.

It has to be pointed out that some of the criteria mentioned above are in fact sets or categories of several criteria. For example, the criterion "satisfaction of the stakeholders" comprises individual criteria of several stakeholders' satisfaction, and even this can be split into satisfaction with various aspects of the project. Also, e.g., the criterion "organisational benefits" may incorporate various benefits. So, and this is clearly shown by the literature, there exist a huge set of different success criteria, which, for transparency reasons, are grouped in success criteria categories. For example, Shenhar et al. (1997) propose a grouping of 13 success criteria in four categories: 1. achieving planned objectives, 2. benefits for the customer, 3. commercial success, 4. future potential.

Some project success criteria are objective, some subjective. For the former ones there exists a natural measurement scale, for the latter ones an evaluation scale has to be elaborated. But independently of the subjectivity or objectivity of the criterion there is always a subjectivity component due to the decision maker as to the interpretation of the linguistic expressions such as "high" success, "low" success, "full" success, "partial" success, etc. This depends in each case on the individual decision, which in turn is a consequence of the situation of the project in question and the preferences of various project stakeholders. In the literature, various approaches are proposed. For example, Yourdon (1997) is of the opinion that 50% "less" or "more" than planned in a negative direction (e.g., less profit more cost etc.) in any of project success parameters means a complete failure (e.g. 50% less scope, more money, more time or less quality). Cheng, Tsai and Sudjono (2012) propose a lower bound of 80%-90% in the achievement of the quality and scope as the minimal requirement for a project to be considered successful. Nahod et al. (2013) formulate the following proposal in this respect (they consider time, budget, scope and customer satisfaction as the aspects which constitute project success):

Table 1: Definition of project success in terms of time

Failure	Almost failure	Almost success	Success
PAD>115%PPD	115%PPD ≥PAD>105%PPD	105%PPD ≥PAD>100%PPD	PAD≤100%PPD

(PAD = project actual duration; PPD = project planned duration)

The definition of project success in terms of budget (i.e. failure, almost failure, almost success and success) is defined analogously to Table 1.

Table 2: Definition of project success in terms of scope

Failure	Almost failure	Almost success	Success
AS<80%PS	90%PS ≥AS>80%PS	100%PS >AS>90%PS	AS≥100%PS

(AS = actual scope; PS = planned scope)

The overall evaluation of the *project outcome* for the project manager should be expressed linguistically: failure, almost failure, partial success and success, and these expressions should be defined with respect to the selected evaluation scale. The overall evaluation of the *customer satisfaction* with project results should also be expressed linguistically: low, rather low, rather high and high, and these expressions should also be defined with respect to the selected evaluation scale.

Another issue in project success evaluation is the method of aggregating the various criteria adopted. In other words, should the various project success aspects be synthesised into one measure, which would evaluate the overall project success, by giving one number, expressing the degree to which the project was successful, according to the suggestion of Sutton (2005) or Shashi et al. (2014)? Or maybe should the different aspects remain separated? Several authors do not synthesise the success measures in various project success aspects (Cheng et al., 2012; Chow and Cao, 2008). We think that this approach is useful for practical applications, but in the end each organisation or each decision maker should find its or his/her own aggregated decision as to whether the project in question was a success or not. However, this aggregation will strongly depend on the decision maker. Each decision maker has preferences regarding his/her projects, often enforced by the projects' environment or the specific situation in which they are realised. The different aspects (such as time, cost, satisfaction of individual project stakeholders, etc.) are never all equally important and their importance should be judged by the decision makers.

Another problem linked to the definition of project success is that projects implemented in different areas have their own project success aspects and groupings. Here we are dealing with R&D projects, which will be the subject of the next section.

3 Success of research and development projects

R&D projects 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 use the existing knowledge in order to create new products or processes (Klaus-Rosińska, 2019). Although the "classical" success measures (time, cost, scope) are or can be important depending on the context (for example, time and cost criteria are important in order to formally account for the project grant), the understanding of R&D project success is much more nuanced, even more nuanced than it was described in the previous section for projects in general.

On the basis of interviews with over 60 managers of R&D projects (a detailed description of the survey and its basic results can be found in Klaus-Rosińska 2019 and Kuchta et al. 2017) we can formulate the thesis that the evaluation of the success of R&D projects can be based on the following groups of criteria (of course, these groups are arbitrary and each decision maker can formulate his or her own proposal):

A. Short-term research success,
B. Long-term research success prospects,
C. Short-term financial success,
D. Long-term financial success prospects,
E. Short-term personal development success,
F. Long-term personal success prospects,
G. Satisfaction of external (to the project team) stakeholders.

It has to be stressed that, according to the project managers interviewed, a successful project does not have to be successful in all the above criteria groups. For example, numerous interviewees share the opinion that the success in one or two of the groups is sufficient, where these "one or two groups" can be any of the above listed ones. This shows that the evaluation of the overall R&D project success has to be very flexible and nuanced, based on the experts' opinion and allowing for different views of different stakeholders (Davis, 2014). Moreover, this shows that an aggregated, universal evaluation of the success of a project might not always be desirable: each stakeholder can choose other criteria groups for the project success evaluation.

We will use the notation $\{g_s\}_{s=1}^{t}$ for the criteria groups, where *t* stands for the number of criteria (for example, the groups A – G listed above). There are dozens of criteria from these groups (e.g. Klaus-Rosińska, 2019; Elkadi, 2013; Eilat et al., 2008; Revilla et al., 2003). Some of them are:

A. Short-term research success
   a. Achievement of the planned research results,
   b. Achievement of other than planned research results,
   c. Demonstration that the selected research direction was incorrect,
   d. Publications with good bibliometric parameters (one criterion per one team member);

B. Long-term research success prospects
   a. Ideas for new research projects,
   b. New cooperation possibilities,
   c. Promising results in progress;
C. Short-term financial success
   a. Satisfying remuneration for individual members of the project team,
   b. Satisfying net cash flow for the organisation where the project was implemented,
   c. New patents developed;
D. Long-term financial success prospects
   a. Prospects of patents,
   b. Prospect of academia-industry cooperation;
E. Short-term personal development success
   a. Satisfaction of the individual project team members with the improvement of personal skills obtained thanks to the project (one criterion per one team member),
   b. Satisfaction of the senior researchers with the development of skills of the junior researchers (one criterion per each couple senior researcher / junior researcher working under his or her supervision);
F. Long-term personal development prospects
   a. New cooperation possibilities (one criterion per each project team member),
   b. New ideas for unassisted research projects (one criterion per each junior project team member);
G. Satisfaction of external (to the project team) stakeholders
   a. Satisfaction of the financing institution,
   b. Satisfaction of the institution(s) which implemented or were partners in the project.

As for the notation of the elements of the criteria groups $\{\mathcal{g}_s\}_{s=1}^{t}$, for each s=1,…,t we will have $\mathcal{g}_s = \{G_r^s\}_{r=1}^{w_s}$, where w_s is the number of elements of the criteria group $\mathcal{g}_s$.

It has to be stressed that all of the above criteria and criteria groups can be satisfied fully, partially or not at all. In order to express this, in the next section we introduce the notion of fuzzy sets.

4 Fuzzy sets and fuzzy rules

According to Zadeh (1965), we can define fuzzy sets to model human understanding of various concepts. Fuzzy sets defined on the set of real numbers are called fuzzy numbers. Many types of fuzzy numbers exist, but here we will consider only two types: triangular and one-sided.

Definition 1: A triangular fuzzy number $\tilde{A} = (\underline{a}, \hat{a}, \overline{a})$ is a feature expressed by means of the membership function $\mu_A: \mathcal{R} \to [0,1]$ such that $\mu_A(x)$ expresses the degree (determined by an expert or a group of experts) to which *x* possesses this feature and

$$\mu_A(x) = \begin{cases} 0 \text{ for } x \leq \underline{a} \\ \frac{x-\underline{a}}{\hat{a}-\underline{a}} \text{ for } x \epsilon (\underline{a}, \hat{a}) \\ 1 \text{ for } x = \hat{a} \\ \frac{\overline{a}-x}{\overline{a}-\hat{a}} \text{ for } x \epsilon (\hat{a}, \overline{a}) \\ 0 \text{ for } x \geq \overline{a} \end{cases} \quad (1)$$

Definition 2: One-sided fuzzy numbers (left-sided or right-sided) are triangular fuzzy numbers such that

a. For a left-sided fuzzy number, $\underline{a} = -\infty$
b. For a right-sided fuzzy number, $\overline{a} = \infty$.

It is important to indicate for which values the membership function takes positive values, that is, to define the support of fuzzy numbers:

Definition 3: The support of the triangular fuzzy number $\tilde{A} = (\underline{a}, \hat{a}, \overline{a})$ is the open interval $(\underline{a}, \overline{a})$, the support of the left-sided fuzzy number is the half-line $(\infty, \overline{a})$ and that of the right-sided fuzzy number is the half-line $(\underline{a}, \infty)$.

For example, in the banking sector (Korol, 2012) the experts of each bank can define their understanding of such terms as "very low", "low", "average", "high" and "very high" financial security, or "very low", "low", "average" , "high" and "very high" yearly income of the potential borrower. Financial security is not easily measurable, so the experts would be asked to use a predefined scale (e.g. from 0 to 5) to define the first five terms. The borrower's yearly income is measurable, so the scale for the last five items would correspond directly to the income values. Figure 1 presents example definitions of the terms, generated on the basis of expert opinions.

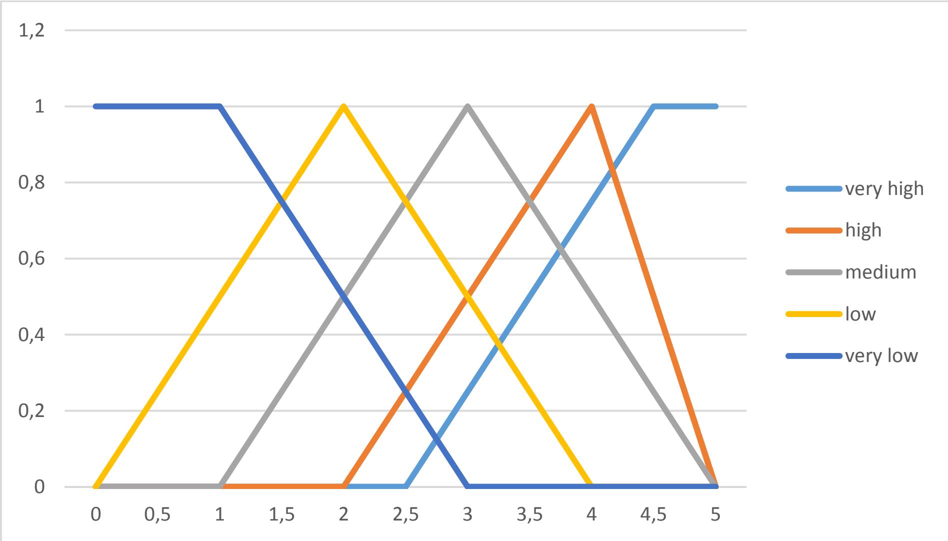

Figure 1: Examples of fuzzy concepts

Source: Author's own elaboration.

Figure1 shows five examples of fuzzy numbers: three triangular, one left-sided and one right-sided. They represent several possible features of financial security or income (measured on the horizontal axis using units which must be predefined, such as hundreds of thousands of dollars for the income or an arbitrary scale for financial security). Each value of the income may have one of the six features fully, partially to a certain degree or not at all. For instance, income 1.5 is not very high at all, not high at all, it is medium to the degree 0.25, low to the degree 0.75 and also very low to the degree 0.75 (according to the experts)

In general, there will be a set of concepts $\mathbb{C} = \{C_i\}_{i=1}^{n}$ (Figure1 refers only to one concept/notion, e.g. either financial security or income) that corresponds to evaluation criteria (in the case of the evaluation of a bank and a potential borrower we would have, for example, the following set $\mathbb{C}$: {age, education, income, type of employment, length of employment, value of the borrower house}) (Korol, 2012). We will also have a set of features (for example, the set {very small, small, medium, big, very big}) $F = \{\tilde{F}_j\}_{j=1}^{M}$, $\tilde{F}_j = (\underline{a}_j, \hat{a}_j, \overline{a}_j)$, with each feature defined by the membership function μ_j^i being either a triangular or a one-sided fuzzy number, according to Definition 1. It is important that for each $\tilde{F}_j$ the corresponding membership function μ_j^i can be different for each element C_i of $\mathbb{C}$ (i.e. the concept "big" can be defined in a different way, for, e.g., income and financial security, it may have other units on the horizontal axis and use a different membership function each time).

Moreover, it is required that for each $i = 1, \dots, n$ and for each element x of $\mathcal{R}^+$ (in the general case the whole set of real numbers can be considered, but here, because of the nature of applications discussed, only non-negative values are taken into account) there exist at least one j_0 such that x belongs to the support of $\mu^i_{j_0}$. This assumption means that for each concept the decision maker has covered all the possible values $\mathcal{R}^+$ with the features: each x has at least one feature from the set F to a positive degree. This condition is satisfied in Figure 1.

In this context it is possible to consider, for each $x \in \mathcal{R}^+$, expressions similar to those used in natural languages, for example "Concept C_i is $\tilde{F}_j$ " for a certain i, , $i = 1, \dots, n$ and j, $j = 1, \dots, k_i$, or − to take a more specific example of the bank – "Income is high".

However, a procedure to generate such sentences in an unambiguous way should be designed, because, as we can see e.g. in Figure 1, a concept may have various features to various degrees. The proposed procedure is as follows: we will say that, by definition, for $x \in \mathcal{R}^+$, concept C_{i_0} is $\tilde{F}_{j_0}$ if $\max_{j=1,\dots,M} \mu^{i_0}_j(x) = \mu^{i_0}_{j_0}(x)$. If more than one j_0 with this property exist, the decision maker will be asked to choose one of them. Thanks to these assumptions, $\mu^{i_0}_{j_0}(x)$ selected in this way will always be positive and unambiguous, thus the statement "Concept C_{i_0} is $\tilde{F}_{j_0}$ " will always be to a certain degree justified and also unequivocal. Using the example given in Figure 1, the income 1.5 will be described as low or very low – this ambiguity will have to be resolved by an expert.

An additional assumption is that the features $F = \left\{\tilde{F}_j\ \right\}_{j=1}^{M}$ are ordered in the sense that either for each i the decision maker prefers C_i to be $\tilde{F}_{j+1}$ than to be $\tilde{F}_j$ for j=1,..M-1 or he or she prefers C_i to be $\tilde{F}_{j-1}$ than to be $\tilde{F}_j$ for j=0,..M) and that the corresponding membership functions are defined correctly. In the case of Figure1 the order follows clearly from the meaning of the concepts used as examples (financial security or yearly income) and the membership functions are "defined correctly" in the sense that for a fixed i, the values $\underline{a}^i_j, j = 1, \dots n$ (and analogously the other parameters defining the membership functions, i.e. $\widehat{a}^i_j, j = 1, \dots n$ and $\overline{a}^i_j, j = 1, \dots n$) defining the membership functions of $\tilde{F}_j$ for C_i are ordered in the sense of the usual ordering of real numbers.

Having defined fuzzy features, we can define fuzzy rules.

Definition 4 (author's own definition): A fuzzy rule R is a statement of the following form:
"If for each j=$1,\dots,m,$ for at least s_j^R elements i from the set $\{1,\dots,n\}$ the statement 'Concept C_i is $\tilde{F}_j$ or more' is true, and for no more than t_j^R elements i from the set $\{1,\dots,n\}$ the statement 'Concept C_i is $\tilde{F}_j$ or less' is true, then take a specific decision" (implicitly: if any of the elements of the selected set is false, do not take any decision yet). The words "or more" and "or less" refer to the assumed order of $\{\tilde{F}_j\}_{j=1}^{M}$.

Let us present an example of a fuzzy rule from the banking sector, which might be used by commercial banks to make decisions about the credit risk of a potential borrower:

Example 1: Let us assume that three criteria are taken into account by the bank: the potential borrower's income, his/her financial security and the interest rate of the credit. Each of the criteria may be very low, low, medium high and very high. Then we might have the following decision rule: "If at least two criteria are medium or more and at least one criterion is high or more and no more than two criteria are low or less, then set the credit risk to low".

In the next section fuzzy numbers and fuzzy rules will be applied to the evaluation of research and development projects.

5 The proposed approach to R&D project success evaluation

In our opinion, it is important to facilitate the evaluation of R&D project success through grouping of the many possible evaluation criteria (presented in Section 3) into homogenous groups (for example, those presented in Section 3) and performing a separate evaluation of project success in each group. An optional aggregation will be performed later as a second step.

Hence, we consider t homogenous groups of R&D success evaluation criteria $\{\mathcal{g}_s\}_{s=1}^{t}$. For each $r=1,\dots,w_s$ we have $\mathcal{g}_s=\{G_r^s\}_{r=1}^{w_s}$. We assume that, for each $s=1,\dots,t,$ $\mathcal{g}_s$ can be fully identified (i.e. all the assumptions are stated) with $\mathbb{C}$ from the previous section. We will use the following procedure (for a selected R&D project $\wp$):

I. SET s:=1;
II. SET $\mathbb{C}:=\mathcal{g}_s$
III. For each G_r^s, $1,\dots,w_s$ find out for which $\tilde{F}_{j_r^s}$ the sentence "G_r^s is $\tilde{F}_{j_r^s}$" (j_r^s=$1,\dots,M$) is true according to the procedure described in the previous section;
IV. IF s=t THEN STOP, OTHERWISE SET s:=$s+1$ and GO TO step II.

The outcome of this procedure is a set of statements of the form "For project ℘ G_r^s is $\tilde{F}_{j_r^s}$ ", for each $s = 1, \dots, t$ and for each criterion $\{G_r^s\}_{r=1}^{w_s}$.

As the next step consider, for each *s*, the criteria group g_s and the corresponding values $\tilde{F}_{j_r^s}$ and ask the experts which rules should be applied to obtain an aggregated evaluation of the fulfilment of the criteria from g_s. The same features $F = \{\tilde{F}_j\}_{j=1}^{M}$ can be used here. Fuzzy rules should be applied here, for example made specific for this case as follows:

Rule R: "If for each *j*=$1, \dots, m$ for at least s_j^R elements *r* from the set $\{1, \dots, w_s\}$ the statement 'G_r^s is $\tilde{F}_j$ or more' is true and for no more than t_j^R elements *r* from the set $\{1, \dots, w_s\}$ the statement 'G_r^s is $\tilde{F}_j$ or less' is true then perform a certain action" (implicitly: if any of the elements of the selected set is false, do nothing). The words "or more" and "or less" refer to the assumed order of $\{\tilde{F}_j\}_{j=1}^{M}$.

The consistency of the rules should be verified by the experts, and metarules deciding which rule to apply if the rules lead to different conclusions should be formulated.

In this step the project ℘ will have been evaluated in the homogenous criteria groups g_s, $s = 1, \dots, t$. The decision maker may stop here and not perform any further aggregation or he or she may decide to use fuzzy rules again in order to obtain an aggregated evaluation of the success of the project.

The proposed approach allows to aggregate evaluations of individual criteria from a homogenous groups into one evaluation for the group (and possibly later into an aggregated evaluation of the whole project success) in a simple (not requiring any complicated mathematical formulae and using expressions similar to those used in natural languages) and flexible form, in which a low satisfaction on some criteria will be compensated by a better behaviour on other criteria.

To sum up, we propose to evaluate the success of R&D projects on the basic of the following criteria tree, applied to each project:

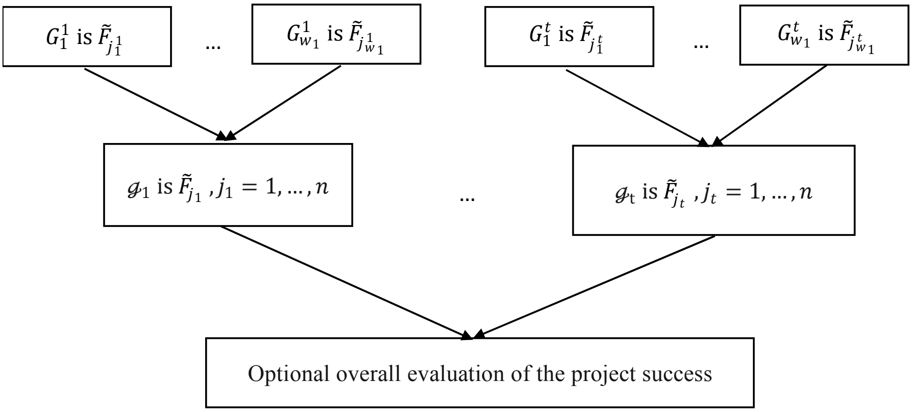

Figure 2: General scheme of R&D project evaluation

Source: Author's own elaboration.

The proposed approach will be illustrated by a case study.

6 Case study of an R&D project

The project entitled "Elaboration of a costing system for university X", of two-year duration, was funded by the Polish Centre of Research and Development. It was implemented in 2011-2012. It was managed by the present author. The objective of the project was to:

- Analyse the costing system used at university X at that time,
- Analyse managerial information provided by the existing system,
- Identify unsatisfied needs for managerial information,
- Identify necessary (existing and missing) sources of entry data for the system
- Elaborate a trial version of the system,
- Implement the system in two selected faculties of the university,
- Elaborate general indications for costing systems at universities.

Various factors contributed to the fact that most of the above objectives were satisfied only partially, to a low or even to a very low degree. Some of these factors were: concern about changes and additional work load among university administration employees, concern about revealing current financial procedures and information, disorder in the data at the university and low progress of data digitalisation. However, this project was considered by the team as a partial success, because other important objectives have been achieved:

- Identification of new research subjects,
- Identification of new opportunities for research cooperation,

- The project contributed to the achievement of PhD and ScD degrees,
- Building a well integrated research team,
- Satisfactory financial inflows for the project team members.

The decision makers of the university itself were not interested in the project at that time (mainly because of lack of time and because of numerous other challenges) and thus were rather indifferent as to its outcome. On the other hand, another, smaller university was selected as a partial substitute, where the above objectives were achieved to a higher degree. The financing institution accepted the results thanks to the continuous flow of information they were obtaining about the problems encountered in the project realisation and the introduction of a substitute university.

Thus, if we refer to the groups of success criteria described in section 3, we can say that the individual success criteria listed in section 3 were achieved to the degree given in Table 1. The evaluation in the last column was calculated using fuzzy rules, whose examples are given below in Table 3.

Table 3: Evaluation of the case study project

Criteria group	**A**	**b**	**c**	**d**	**Overall evaluation of success in the criteria group**
A	low	medium	irrelevant	low	low
B	very high	very high	high	-	very high
C	very high	medium	irrelevant	-	high
D	irrelevant	high	-	-	high
E	very high	very high	-	-	very high
F	high	very high	-	-	high
G	medium	medium	-	-	medium

Source: Author's own elaboration.

The following fuzzy rules were used here (among others):

For the criteria group A:

- If at least two of the criteria are high or more and no more than two criteria are low or less, the success in the whole group is high (this rule led to no conclusion in this case);
- If at least two criteria are low or less and at least one is medium or less, the success of the whole group is low.

For the criteria group B:

- If at least three of the criteria are very high or more and at least one criterion is high or more and no more than one criterion is medium or less, the success in the whole group is very high.

Similar rules were used for the other criteria groups. In the last step, the following rule was used to evaluate the success for the whole project:

- If at least two of the criteria are very high or more and at least one criterion is high or more and no more than three criteria are medium or less, the success of the project is high.

Thus, the experts, using their own rules, were able to judge the project success in a flexible way, expressing their opinion that the overall success of the project is high, even though the main research objectives were not achieved. Another expert group might have been of a different opinion. But it seems that in the case of research projects it is especially important to be flexible in their evaluation, because the understanding of their success is often ambiguous.

7 Conclusions

The paper proposes a flexible, easy to follow procedure for the assessment of R&D projects, which can be used for other project types as well. The procedure is based on expert opinion. The experts have to formulate rules which use language similar to natural languages. The other basis of our method are evaluation criteria of project success, which should be of various nature. This paper proposes a set of such criteria and refers to the literature where many more criteria can be found.

Setting criteria and rules is essential for the method to work. The method has to be constructed in detail and carefully tested in each specific context: in each organisation or group implementing R&D projects, possibly also in institutions funding such projects. This is because in the final analysis the success of a project has to be judged with respect to the strategy of individual institutions and groups. Thus the proposal formulated here should be regarded as a first step towards a complete and flexible system of evaluation of R&D project success.

The main method of further research should consist of case studies with active participation of various experts. In this paper we have discussed one case study, in which the role of experts was taken by the project manager and the project team. Undoubtedly, more exhaustive case studies are needed.

Acknowledgements

This research was supported by the National Science Centre (Poland), under Grant 394311: “Selected methods supporting project management, taking into consideration various stakeholder groups and using type-2 fuzzy numbers”.

References

Ashley D.B., Laurie C.S., Jaselskis E.J. (1987), *Determinants of Construction Project Success*, Project Management Journal, 18(2), 69-79.

Baccarini D. (1999), *The Logical Framework Method for Defining Project Success*, Project Management Journal, 30(4), 25-32.

Baker B.N., Murphy D.C., Fisher D. (1988), *Factors Affecting Project Success*, [in:] D.I. Clenad, W.R. King (eds.), *Project Management Handbook*, Von Nostrand Reinhold, New York, NY.

Belassi W., Tukel O.I. (1996), *A New Framework for Determining Critical Success/failure in Projects*, International Journal of Project Management, 14(3), 141-151.

Camilleri E. (2011), *Project Success: Critical Factors and Behaviours*, Gower Publishing Company, Surrey, UK.

Chan A.P.C., Chan A.P.L. (2004), *Key Performance Indicators for Measuring Construction Success*, Benchmarking: An International Journal, 11(2), 203-221.

Cheng M.-Y., Tsai H.-C., Sudjono E. (2012), *Evolutionary Fuzzy Hybrid Neutral Network for Dynamic Project Assessment in Construction Industry*, Automation in Construction, 21, 46-51.

Chow T., Cao D.-B. (2008), *A Survey Study for Critical Success Factors in Agile Software Projects*, Journal of Systems and Software, 81, 961-971.

Davis K. (2014), *Different Stakeholder Groups and Their Perceptions of Project Success*, International Journal of Project Management, 32(2), 189-201.

Eilat H., Golany B., Shtub A. (2008), *R&D Project Evaluation: An Integrated DEA and Balanced Scorecard Approach*, Omega, 36(5), 895-912.

Elkadi H. (2013), *Success and Failure Factors for E-government Projects: A Case from Egypt*, Egyptian Informatics Journal, 14(2), 165-173.

Freeman M., Beale P. (1992), *Measuring Project Success*, Project Management Journal, 23 (1), 8-17.

Frese R., Sauter V. (2003), *Project Success and Failure: What is Success, what is Failure, and How Can You Improve Your Odds for Success*, [Online] cited after Camilleri (2011).

Greer M. (1999), *Handbook of Human Performance Technology*, CA: Jossey-Bass, San Francisco.

Kerzner H. (1992), *Project Management: A Systems Approach to Planning, Scheduling and Controlling*, Van Nostrand Reinhold, New York, NY.

Khan K., Turner J.R., Maqsood T. (2013), *Factors that Influence the Success of Public Sector Projects in Pakistan. Proceedings of IRNOP 2013 Conference, June 17-19, 2013*, BI Norwegian Business School, Oslo, Norway.

Klaus-Rosińska A. (2019), *Sukces projektów badawczych i badawczo-rozwojowych*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław [in print].

Korol T. (2012), *Fuzzy Logic in Financial Management*, https://www.intechopen.com/profiles/105028/tomasz-korol

Kuchta D., Betta J., Jastrzębska J., Frączkowski K., Gładysz B., Prałat E., Ptaszyńska E., Rola P., Walecka-Jankowska K., Ropuszyńska-Surma E., Skomra A., Ryńca R., Klaus-Rosińska A., Mrzygłocka-Chojnacka J. (2017), *Success and Failure Factors of R&D Projects at Universities in Poland and France*, [in:] A. Nowak, Z. Wilimowska (eds.), *Business Risk in Changing Dynamics of Global Village: Proceedings of 1st International Conference on Business Risk in Changing Dynamics of Global Village, 26-27 April 2017*, Publishing Office, University of Applied Sciences, Nysa, 253-278.

Lim C.S., Mohamed M.Z. (1999), *Criteria of Project Success*, International Journal of Project Management, 17(4), 243-248.

Mir F.A., Pinnington A.H. (2013), *Exploring the Value of Project Management: Linking Project Management Performance and Project Success*, [to be published in International Journal of Project Management].

Nahod M.-M., Vukomanovic M., Radujkovic M. (2013), *The Impact of ICB 3.0 Competences on Project Management Success. In 26th IPMA World Congress, Crete, Greece, 2012*, Procedia: Social and Behavioral Sciences, 74, 244-254.

Pinto J.K., Slevin D.P. (1988), *Critical Success Factors in Successful Project Implementation*, IEEE Transactions on Engineering Management, 34(1), 22-27.

Raz T., Shenhar A.J., Dvir D. (2002), *Risk Management*, *Project Success and Technological Uncertainty*, R&D Management, 32(2), 101-109.

Revilla E., Sarkis J., Modrego A. (2003), *Evaluating Performance of Public-private Research Collaborations: A DEA Analysis*, Journal of the Operational Research Society, 54(2), 165-174.

Shashi K.N.R., Nai T.R.G., Suma V. (2014), *SLI: A New Metric to Determine Success of a Software Project. 2014 International Conference on Electronics and Communication Systems*, ICECS 2014.

Shenhar A.J., Dvir D., Levy O. (1997), *Mapping the Dimensions of Project Success*, Project Management Journal, 28(2), 5-13.

Sutton B. (2005). *Why Projects Fail: Mastering the Monster*, cited after Camilleri (2011).

Thomas G., Fernández W. (2008), *Success in IT Projects: A Matter of Definition?*, International Journal of Project Management, 26(7), 733-742.

Thomsett R. (2002), *Project Pathology, Causes, Symptoms and Patterns of Project Failure*, cited after Camilleri (2011).

Turner J.R. (1994), *Editorial: Project Management Future Developments for the Short and Medium Term*, International Journal of Project Management, 12(1), 3-4.

Wateridge J. (1998), *How Can IS/IT Projects be Measured for Success?*, International Journal of Project Management, 16(1), 59-63.

Westerveld E. (2003), *The Project Excellence Model: Linking Success Criteria and Critical Success Factors*, International Journal of Project Management, 21, 411-418.

de Wit A. (1988), *Measurement of Project Success*, International Journal of Project Management, 6(3), 164-170.

Yourdon E. (1997), *Death March: The Complete Software Developer's Guide to Surviving Mission Impossible Projects*, NJ: Prentice Hall, Upper Saddle River.

Zadeh L. (1965), *Fuzzy Sets*, Information and Control, 8(3), 338-353.