Uncertainty occurrence in projects and its consequences for project management

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Abstract: Based on a survey (with 350 respondents), the occurrence of uncertainty, defined as incomplete or imperfect knowledge in the project planning or preparation stage, was described and quantified. The uncertainty with respect to customer expectations, project result, methods to be used, duration and cost of project stages, and (both human and material) resources was considered, and its consequences for project management and entire organizations were analysed. The results show that the scope of uncertainty in projects cannot be neglected in practice and requires the use, in the project planning or preparation stage, and during the whole project course, of advanced project and uncertainty management methods. The questionnaire used in the document is recommended to be applied to organizations in order to measure and track the scope of uncertainty in the projects being implemented and adopt a tailored approach to uncertainty management. Agile approaches seem to be highly recommendable in this regard. Future research directions are proposed, including the application of a special type of fuzzy numbers to project management.

Keywords: knowledge about project, project success, customer requirements, project uncertainty, project planning.

1 Introduction

Uncertainty, along with risk, has been the subject of research for many years and has been defined in the literature in various ways, also in the context of project management (see, e.g., [1–3]). This is so because risk and uncertainty (independently of the specific definition adopted) are fundamental issues in project management, addressed both by researchers [4, 5] and by professional project management standards [6]. The relatively high rate of project failures, together with an analysis of their causes [7–9], indicates that project risk and uncertainty management should be the focus of project managers and teams. However, optimism bias [10, 11] often prevents project managers and teams from applying enough effort to this aspect of project management in the project planning (or preparation) stage. As a result, project teams begin to work on projects using unrealistic project plans or an erroneous image of what the project is aiming at.

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At the same time, they are unaware of their lack of knowledge, which inevitably leads to project failure. Therefore, the objective of this paper is to show that optimism is often not justified because uncertainty in the project occurs fairly often in practice. It is pretty common that in the project planning or preparation stage, the information about the project is uncertain, and therefore the plans and the expected consequences of the projects for the organisations must be treated with the necessary caution. This statement will be proved with respect to various manifestations of project uncertainty. On top of that, the objective is to propose a tool that can be used to measure and quantify the degree of uncertainty (in its various manifestations) in projects that have already been realized in a given organization, which may be helpful to improve the organizational project management process.

Similar research is presented in [3], but in that approach, the uncertainty was measured without considering the differences between the knowledge (about issues that must be known in the project planning or preparation phase) before the project starts and after the project ends. In our opinion, this aspect is an important measure of uncertainty because a piece of information (e.g., on a project parameter) available in the project planning phase can be seen as certain only if it does not change with time in a substantial way.

In this paper, we adopt the approach of [1, 12]: we define uncertainty as the state of not knowing for sure, and place project uncertainty in the framework of seven 'Ws' questions asked with respect to projects in [12]: Who? (who are the parties involved?); Why (what do the parties want to achieve?)? What? (what is the deliverable product the parties are interested in?); Which way (how will the plans in each lifecycle stage deliver what is needed?); Wherewithal (what key resources are needed to achieve execution of the plans?); When? (when do all relevant events have to take place?); Where? (where will the project take place?). Seen in this way, uncertainty means that we do not have full knowledge at the project planning or preparation stage of how to answer the respective questions correctly and precisely. Two cases will be referred to: one when, in the given moment, we are aware of our lack of knowledge, and the other one when we will be aware of it only in the future. Our research refers specifically to the aspects What, Which way, and Wherewithal.

The outline of the remainder of this paper is as follows: In Section 2, we explain our research methods. As we chose to measure the knowledge present among the project team in two steps – one referring exclusively to the period before the project started and one referring to the differences between the situation before the project started and the actual outcomes – the results of the questionnaires are analysed in two respective steps. Thus, in Section 3, we present the results of basic statistical analyses referring to the knowledge about the project in the period before its start, and in Section 4, we discuss the results of basic statistical analyses referring to the differences in knowledge before the project started and after the completion of the project. In Section 5, we present a discussion and some conclusions.

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2 Research Methods

2.1 Measurement of knowledge available to the project team

The tool used was a questionnaire measuring the level of knowledge about selected project elements present among the project team. We had to decide how to measure this aspect in a way that would allow us to expect the majority of respondents to give reliable answers. We selected the following measures:

a) Regarding the time before the project start: the degree of agreement among project team members as to the expectations of the customer and the expected project result. If project members were not in agreement as to what the customer expected or what the project result should have been, it is legitimate to conclude that they did not really understand the project and the proper way of implementing it. Therefore, they did not really know what they were supposed to do.
b) Regarding the time before the project start: the assessed level of knowledge of individual project features (like cost, duration, etc.) present among the project team. If the respondents did not think that they knew the respective features of the project well before the project started, it is also legitimate to conclude that they did not really know how to implement the project properly.
c) Regarding the time after project completion: the end-start differences in customer expectations. If, after the project had ended, it turned out that the customer had different expectations than those expressed before the project started, it would be difficult to claim that the project team knew what it meant to terminate the project with success.
d) Regarding the time after project completion: the end-start differences in various project parameters and features. If the actual project realisation was substantially different from the project plan (with respect to time, cost, resources, etc.), it would be difficult to claim that the project team knew what to do to bring the project to success.

2.2 Questionnaire-based survey

The primary research method used was interviews structured as presented in section 2.1. The principal goal of the interviews was to find out whether and to what degree, the project team knew before the projects started what the ultimate customer expectations were and what exactly to do to satisfy them. The interviews were conducted in 2020. A total of 350 Polish companies/organisations were surveyed, including 118 micro, 131 small, 71 medium, and 30 large ones (Table 1). The respondents were selected among project managers or heads of the companies/organisations.

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Table 1. Size of organisations from the research.

Company/Organisation Size	Number	Percentage
Micro (below 10 people)	118	33.7
Small (10–49 people)	131	37.4
Medium (50–249 people)	71	20.3
Large (over 250 people)	30	8.6
Total	350	100.0

The CATI [13] method was used for the interviews.

In an attempt to characterise, at least to a certain degree, the organisations represented by the respondents, one question was asked about the average duration of the projects implemented by the organisation; this could range from several days to several years (Table 2).

Table 2. Average project duration in the organization**.**

Duration class	A few days	Month	Quarter	Half-year	Year	A few years	Total
Percentage	15.9	13.9	17.6	18.2	19.3	15.2	100

Another question characterised the type of project management applied in the organisations. Three options were proposed [14]:

- traditional (waterfall) project management;
- agile/extreme project management;
- a combination of the two.

It turned out that all three types of project management were used in all the organisations represented in the survey. However, specific types of project management approaches prevailed in individual organisations. In 32% of the organisations, the most frequently used management type was the traditional approach, in 7%, the agile/extreme one, and in 11% a combination of traditional/agile.

In the next stage of the interview, an attempt was made to determine the knowledge present among the project team. As indicated above, we decided to investigate this problem in two steps (one referring to the time before the project start and one referring to the differences between project start and project end) through four types of information we hoped to gather:

I. the indicator (for the time before the project started) of agreement among the project team as to what the customer expected or what the project result should be;
II. the assessed level of knowledge (for the time before the project started) of the project team about individual project features (cost, duration, etc.);
III. project end-start difference in customer expectations;
IV. project end-start difference in individual project features.

Let us now present the details of the questionnaire used in parts I, II, III, and IV, together with the variables and scales used.

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Part I (differences of opinion among members of the project team before the project started) consisted of two question groups:

- differences of opinion among project team members as to the expectations of the customer (variable D_ClientExp);
- differences of opinion within the project team as to the outcome of the project (variable D_Results).

The respondents were asked to assess the differences on a Likert scale, with the following meanings: 1 - practical lack of differences; 2 - very small differences; 3 - small differences; 4 - medium differences; 5 - large differences; 6 - very large differences; and 7 - substantial differences.

Part II (level of project team knowledge before the project started) covered the following aspects:

- knowledge of the methods and technologies needed to implement the project (K_Methods);
- knowledge of the time needed for individual project stages (K_Time);
- knowledge of the costs of implementing individual project stages (K_Cost);
- knowledge of the appropriate quantity of human resources (K_PeopleNo);
- knowledge of the needed human resource competencies (K_PeopleComp);
- knowledge of material resources needed (K_MatRes).

The assessments were made on the same 7-level Likert scale, with the following meanings: 1 - almost none; 2 - very small; 3 – small; 4 – medium; 5 – large; 6 - very large; and 7 - complete. In each case, when the answer was four or less (i.e., the level of knowledge was medium or lower), the respondents were asked whether lack of knowledge was the reason for disagreement or conflicts in the project team. There were two possible answers: yes or no.

In part III, the project managers defined the differences between the expectations of the customer at the beginning and the end of the project (D_StartFinish). These differences were assessed on the same 7-point Likert scale as in Part I.

Part IV, devoted to the differences between selected project features in the planning stage of the project and after its completion, was applied only with respect to the projects for which the responses “medium” or more were given in part II. We asked about the following differences:

- between the planned and achieved results (D_StartFinish_Results);
- between the methods or technologies planned for use in the project and those actually used (D_StartFinish_Methods);
- between the planned and actual cost of individual tasks (D_StartFinish_Cost);
- between the planned and actual quantity of human resources needed for project tasks (D_PeopleNo_StartFinish);
- between the planned and actual human resources competencies needed to perform project tasks (D_StartFinish_PeopleComp);
- the planned and actual quantity of material resources needed to perform project tasks (D_StartFinish_MatRes).

These differences were assessed on the same 7-point Likert scale as in Part I and III. To analyse the data retrieved from the surveys, we applied the software package SPSS (https://spss.pl/spss-statistics/).

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3 Results of basic statistical analyses related to project start (parts I and II of the questionnaire)

3.1 Differences of opinion among the project team regarding customer expectations and expected project result (part I)

Respondents were asked about the differences of opinion concerning customer expectations (D_ClientExp) and what the project result (D_Results) should be. The highest values on the Likert scale corresponded to the highest differences and the lowest values to the lowest ones. The distributions of both variables (D_ClientExp, D_Results) are illustrated in Table 3.

Table 3: Descriptive statistics of variables D_ClientExp and D_Results**.**

Variable	Mean	Median	Mode	Variance	Differences	
					1,2,3	4,5,6
D_ClientExp	2.71	2.00	1.00	2.96	69%	31%
D_Results	2.75	2.00	1.00	2.74	70%	30%

The two probability distributions of the differences of opinion within the project team are right-handed. No outliers were identified. Estimators of the expected values of opinion differences in both analysed dimensions (D_ClientExp, D_Results) are equal to approx. 2.7, and of the variance to approx. 2.8. Median Me = 2, which in the Likert scale means very small differences. So, the level of uncertainty in the aspect considered here may seem not to be very high: in about 70% of the projects, the differences of opinion were almost none, small or very small. However, in about 30% of the projects, the differences of opinion here were medium, large, very large, or substantial. The last statement is very important. In about 30% of projects, the project team members were definitely not in agreement (before the project started) as to what the customer wanted and where the project was heading at. In all of these cases, it would be difficult to claim that the project team had complete knowledge about the project.

Let us now look at the assessment of the level of knowledge about project details prior to project start.

3.2 Level of project team knowledge concerning individual project parameters (part II)

The respondents were asked about the level of the project team's knowledge (during project planning) of various aspects of the project necessary for a good project plan. The higher the answer value, the higher the knowledge evaluation. The following variables were used: K_Methods (methods to be used in the project), K_Time (duration of individual project stages), K_Cost (cost of individual project stages), K_PeopleNo (number of human resources needed), K_PeopleComp (competences of human

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resources needed) and K_MatRes (amount of material resources needed). Descriptive statistics of the probability distributions are given in Table 4.

Table 4. Characteristics of probability distributions of the knowledge of the project team about the project before its start.

Level of knowledge	Mean	Median	Mode	Variance	Level of knowledge (Likert scale)	
					1,2,3,4	5,6,7
K_Methods	5.71	6.00	6	1.49	13%	87%
K_Time	5.64	6.00	6	1.59	13%	87%
K_Cost	5.40	6.00	6	1.77	22%	78%
K_PeopleNo	5.47	6.00	5	1.58	20%	80%
K_PeopleComp	5.65	6.00	5	1.14	12%*	88%
K_MatRes	5.59	6.00	6	1.41	15%	85%

* no “almost no knowledge” level was observed

All probability distributions are left-handed with a median equal to 6 (on the Likert scale - very high level of knowledge). The means are about 5.5, and the modes 5 or 6. So again, the first impression might be that the knowledge level with respect to project plan details was relatively high. It is essential to underline, however, that there is a considerable group of projects (between 13% and 22%) for which the level of knowledge in some aspects was medium or less. This means that, in a relatively large portion of projects, the project team did not really know how to implement the project – for example, in more than 20% of the projects examined, the level of knowledge about the cost of individual project stages could not be described as large, and the same is true for the knowledge about the needed human resources and so forth.

We also observed unusual project teams (outliers) in which the level of knowledge was very small. This is especially true for costs (5% of projects were characterised by a small or very small level of knowledge, and 4% by almost none). In terms of knowledge about methods and technologies, time of implementation of individual project stages, and appropriate quantity of human or material resources, there were several projects with the respective knowledge at the "almost none" level. This means that organisations, on some occasions, deal with projects where the knowledge of how to implement them is extremely low.

The next section is devoted to the differences between the knowledge accessible to the project's team before the project started and after it has finished.

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4 Differences between the knowledge in the project planning stage and after project completion (parts III and IV of the questionnaire)

Here we present the results regarding the differences between the knowledge accessible in project planning stage and after project completion. The occurrence of these types of differences would indicate that uncertainty was present in the project planning stage.

4.1 Differences in customer expectations expressed before the project start and after project completion (part III)

Here we present the results regarding the differences in customer expectations as expressed prior to and at the end of the project. If they were significant, the project team would certainly have been unable to know exactly how to implement the project. The distribution of the differences between the expectations of the customer at the beginning and at the end of the projects is presented in Table 5.

Table 5. Characteristics of probability distributions of differences of customer expectations

Area	Mean	Median	Mode	Variance	Differences of opinion (the Likert scale)		
					1, 2	3, 4, 5	6, 7
D_StartFinish	1.97	2.00	1	1.54	79%	18%	3%

The probability distribution is right-handed. The estimator of the expected value of the differences in customer expectations (D_StartFinish) is 1.97, and the variance estimator is 1.54. The median Me = 2, which in the Likert scale indicates very small differences. The largest fraction of projects (79%) includes those in which the differences in the expectations of the customer at the beginning and end of the project were almost none or very small. However, if we distinguish projects in which the differences in customer expectations between the project beginning and project end were not very small, we arrive at a rather high percentage of 21%. In addition, numerous outliers were identified, where the uncertainty was much higher. Indeed, in 3% of projects (extreme outliers), there were very large or substantial differences. This means that, in a certain group of projects, the customer may change their vision (or the way of communicating it) in a substantial way, so it would be difficult to claim the project team was able to know what to do at the project beginning.

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4.2 Differences between selected project plan details and the reality (part IV)

The managers of the projects in which the differences in the expectations of the customer at the beginning and end of the project were not negligible (i.e., medium, large, very large, or substantial) assessed the level of differences between the expected and actual project results as well as the differences between the planned and actual values of the various project plan elements (the same ones were considered in part II of the questionnaire). The respective variables were introduced in Section 2.

Table 6 provides estimates of the probability distribution parameters of the respective differences.

Table 6: Statistical characteristics of the distribution of the differences between project plans and the actual outcomes.

	Median	Mode	Variance	Differences (Likert scale)	
				1,2,3	4,5,6,7
D_StartFinish_Results	3.0	2	1.71	57%	43%**
D_StartFinish_Methods	2.5	2	1.40	46%*	54%**
D_StartFinish_Time	3.0	1	1.74	40%*	60%
D_StartFinish_Cost	2.5	1	1.93	52%	48%**
D_PeopleNo_StartFinish	2.5	2	1.86	46%*	54%**
D_StartFinish_PeopleComp	2.5	2	1.72	75%*	25%**
D_StartFinish_MatRes	2.5	2	1.96	64%*	36%**

* the level “almost none," ** the level “substantial differences” was not observed

In all the analysed categories, the expected value of the differences between the different project aspects at the beginning and the end of the project is the same: about 3.6 (on a scale of 1–7), and the variance is equal to about 1.75. In 20% to 60% of the projects, the differences between the plan and the reality were at least medium. This means that, in a considerable group of projects, it was impossible that the project team could have possessed fairly good knowledge about the project.

Outliers were observed in the case of such categories as methods and techniques, time, and people’s competencies. They correspond to projects with very large or substantial differences between the project plan and the actual outcomes. In such projects, complete knowledge about the project was certainly not present among the project team before the project started.

5 Discussion

The study started with the investigation of various aspects of uncertainty in the sense of lack or imperfection of knowledge. In each of the investigated aspects of uncertainty, it was shown that, although in most projects the uncertainty was not acute, in each case

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there was a considerable group of projects where the given uncertainty manifestation had such an intensity that it was bound to considerably reduce project success probability. The cardinality of the “problematic” group of projects depends each time on the thresholds we choose while defining such a set. For example, should it comprise only big and very big differences or medium differences too? Only almost none and a very small level of knowledge, or small and medium too? In our analysis, we took arbitrary decisions in this regard, but in each case, the decision-maker should take their own decision, depending on the level of each uncertainty manifestation they accept and the level they would prefer to avoid by using relevant project management methods. Independently of the thresholds, we identified several extreme cases - projects (outliers) where the respective aspect of uncertainty was present at the highest possible intensity level and which were certainly extremely difficult to manage, whatever the uncertainty acceptance level is chosen.

The first aspect investigated was the differences of opinion among the project team concerning the customer expectations and the project result (the element “What” from [12]). This aspect has not been investigated in the literature in the context of project uncertainty so far. As far as the investigated sample is concerned, in 30% of projects, these differences were medium or more, and in less than 30% of projects, they were judged as "practically nonexistent." The last statement means that there were some differences of opinion about the two aspects among the members of the project team in more than 70% of projects. In such a high percentage of projects, the project team was not completely unanimous as to what the project was aiming at. Such uncertainty may lead to a considerable loss of time, effort and enthusiasm. Respective methods of requirements management [16] and of making imprecise requirements precise [17] should be applied.

The next aspect taken into account was the knowledge the project team had (in their own opinion) about various project parameters and other aspects before the projects started. The following items were considered:

- Methods to be used (item Which way from [12]): here, in 13% of projects, the knowledge was judged to be medium, small, very small, or almost none, and in less than half of the projects the knowledge was seen as very high or complete. This means that in the case of more than 50% of the projects, the methods to be used were not fully known before the project started. Such situations require special, Agile-oriented management approaches [20]. It has to be underlined that two outliers were identified here: projects for which the knowledge of the methods to be used was judged as being very small;
- Duration of individual project stages (item When from [12]): the distribution is here similar to that of methods. This shows that in over 50% of projects, advanced methods of time management should be applied – without them, the work in the project and in the whole organization executing the project is difficult to schedule. Approaches like Agile management [14] or Critical chain [19] are recommended. Four outliers (with very small knowledge) were identified;

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- Cost of individual project stages (item Wherewithal from [12]): here, the uncertainty appeared to be the most intense. In 22% of the projects, the knowledge in this aspect was evaluated as being less than medium, in 9% (which constituted 31 projects) as less than small, and in 1% (which constituted four projects) as very small or practically nonexistent. In less than half of the projects, the knowledge was seen as very high or complete. Uncertainty linked to project cost may lead to serious financial problems in the project or even in the whole organization. It seems that apart from advanced methods of project cost estimation [20, 21] and Agile approaches, advanced methods of uncertainty management should be taken into account in project cost management [12];
- The number of necessary human resources (item Wherewithal from [12]): here, the uncertainty also appeared to be very intense: the knowledge in this aspect was seen as being less than medium in 20% of projects and only in about 40% of projects it was evaluated as being very high or complete. In fact, in many projects, e.g., IT projects, the project cost is closely related to the number of human resources used; thus the similarity of the situation in this and the previous aspect is not surprising. This type of uncertainty may lead to serious delays (due to the lack of necessary personnel) or additional costs (due to outsourcing necessity). Here methods of human capacities and work velocity recording [14] should be applied in order to avoid such a high level of uncertainty in planning the number of human resources. One outlier with very small knowledge was identified in this aspect;
- Necessary human competencies (item Wherewithal from [12]): here, the distribution turned out to be similar to that of methods and time. The consequences of this type of uncertainty will be similar to those identified in the area of the number of human resources. Specialized methods of human resources planning [22] would be a remedy;
- Amount of necessary material resources (item Wherewithal from [12]): in 15% of cases, the respective knowledge was less than medium, with one outlier characterized by very small knowledge. Material resources planning is very important, especially in cases when the lead time between the placement of an order and delivery is high or when time-consuming public procurement procedures are necessary. Reserves or other remedies have to be applied in order, on the one hand, to not run short of materials and on the other, not to be left with unnecessary inventory [23].

The incomplete knowledge in the planning or preparation stage results not only in a shortage or surplus of resources or the necessity to introduce big changes with respect to the project plan but may also have an influence on human relationships and thus on team spirit – which is an important project success factor [24]. In order to evaluate the scope of the negative influence of uncertainty on project spirit, we asked those respondents who indicated that the level of knowledge before the project started was, in at least one aspect, small, very small, or almost none, whether this lack of knowledge led to disagreements in the project team. The results are presented in Table 9.

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Table 9. Projects in which, due to incomplete knowledge, there were conflicts in the project team.

Incomplete knowledge in terms of	Fraction of projects in which the incomplete knowledge resulted in conflicts
Time	45.2%
Number of human resources	42.4%
Competencies	57.5%
Material resources	56.3%

In about half of the projects with incomplete knowledge, there appeared to be disagreements caused by this uncertainty type. This means that uncertainty (defined as incomplete knowledge), apart from the obvious negative influence on cost and time (due to necessary changes or incorrect amount of resources), may also deteriorate the team spirit. As the intensity of uncertainty is non-negligible, advanced methods of project team spirit evaluation and management have to be used in everyday project management practice [25].

The next aspect taken into account was uncertainty (lack of knowledge) measured by the “end-start” differences in the aspects considered above. As we mentioned earlier, this problem has not been considered so far in the literature on uncertainty in projects. The project managers in whose projects the expectations of the customer changed during the time of project duration considerably (at least to the medium degree, which happened in 11% of cases) declared that at least medium differences between the final and the planned values or methods had occurred: in 60% of projects for the duration of project stages, in about 50% of projects for methods, cost and number of human resources, and in about 30-40% of projects for the other aspects. This shows that the lack of certainty observed on the customer side results in considerable uncertainty for the project team in the project planning stage. In the case of methods, time, and competencies, several outliers were observed, where the respective differences were very high.

6 Conclusions

To sum up, uncertainty, understood as the lack of knowledge is present in the planning or preparation stage of projects to a non-negligible degree. The frequency values will depend on the choice of the definition of the notion "negligible," but in any case, we will be talking about dozens of percentages of projects with substantial uncertainty. Also, the fact that outliers with extreme uncertainties were observed should not be forgotten. An outlier may seem insignificant in statistical terms but may be the opposite in practical ones: it may be a project of utmost strategic importance or high budget, where the extreme lack of certainty in the planning stage will be reflected in its failure, which in turn may even be devastating for the organization as whole (for its reputation or financial situation).

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The questionnaire used in the research presented in this paper (or a similar one, a combination with that from [3] would be advisable) could be used in each organization with respect to already finished projects within a certain project type so that the uncertainty scope linked to various project aspects in the given organization (and its changes) can be determined and described. Other project uncertainty management methods should be also involved. A track of uncertainty management tools that have been used and could be used (according to [12]) should be kept, so that an adequate choice of uncertainty management methods for the organization and for the given project type can be made and continually updated.

As far as research on project uncertainty management is concerned, it would be advisable to introduce Z fuzzy numbers, or its more general version - Z* augmented fuzzy numbers [25], to the project planning process. These numbers combine the features of "traditional" fuzzy numbers [26] (applied to project management for decades [27]), which allow modeling of uncertainty and partial knowledge (e.g., uncertain duration of a project task) with the possibility to quantify the context in which the fuzzy information was given (thus, e.g., the experience and optimism degree of the person who is the information source, the measured uncertainty scope for a given project type in a given organization and the moment when the information was received), in order to obtain an adjusted representation of uncertain information.

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