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Complexity Measurement in Engineering Projects Using Factor Analysis and the Single Multi-Attribute Rating Technique Exploiting Ranks (SMARTER)

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Abstract: A lot of problems that emanate from complexity could have been mitigated or even avoided, if the factors that render a project complex and the risks that they induce, were fully comprehensible in order for a more appropriate management process to be established. The aim of this study is the comprehension of the meaning of complexity in engineering projects through the identification of the factors that affects it based on which a project complexity measurement model is proposed. To that end an extensive literature review has been conducted in order to detect as many factors already identified by previous researchers as possible and to categorize them in a way that can integrate the existing theoretical and empirical approaches. Through that study, 21 factors that contribute to the complexity of engineering projects were distinguished. Afterwards, following the results of a questionnaire survey that was carried out and upon implementing factor analysis on its data, 7 key factors were discerned as the main components of the complexity variables. Finally, using a simplified method of multiple-criteria decision analysis, namely Single Multi Attribute Rating Technique Exploiting Ranking – SMARTER, a practical and approachable model of complexity measurement has been introduced, named Complexity Level Indicator – CLI.

Keywords: Project Complexity, Factor Analysis, Simple Multi-Attribute Rating Technique Exploiting Ranks (SMARTER)

1. Introduction

Complexity in engineering projects is a factor that shall be especially taken into account by the project manager as it could be considered a source of uncertainty and a risk inducer. In recent years, project managers are asked to deal with the implementation of engineering projects in an increasingly complex context from a technical and organizational perspective. For that reason, it would be of the utmost importance for them to have the ability to assess in a quick and effective way the complexity level of each project in order to focus on the factors that are going to evoke the majority of the problems.

The complex nature of engineering projects can be easily sensed by an experienced professional and located in everyday engineering activity. A project itself, as a system and an entity, as well as its management and the necessary processes in order for it to be fulfilled, are characterized by a high level of complexity. However, it is still unclear what exactly complexity is and what factors insinuate it into an engineering project. Recently a large number of papers related with project complexity has been published denoting the importance of the concept of complexity in modern project management. However, there has been espied a lack of consensus on a commonly accepted definition of complexity in engineering projects [1]. It is easily understood throughout a literature review that there is a lack of a concrete and unambiguous definition of engineering project's complexity [2]. There is no clear and straightforward segregation between a complex, a complicated, a difficult project or a project implemented under a high level of uncertainty [3]. Thus, in spite of the fact that the complexity of a project itself as well as the complex nature of the environment in which it is implemented affects the whole decision making approach during the project management process, the concept of complexity itself most of the times is interpreted instinctively or taking into consideration previously implemented projects' practices [4]. For that reason, project complexity as a concept is combined or confused with uncertainty that is involved within a project either as a whole or partially. Current bibliography connects complexity with complicated situations and / or interrelations between various parts of the project.

Within the same framework, it is commonly agreed that there is no generally accepted model to assess complexity as a measure. A lot of authors have tried to define a project complexity measurement tool in order to identify complicated situations and to assist the whole process of decision-making. Several project complexity measures have been introduced trying to grasp to the greatest possible extend the wide spectrum of complexity. However, it has not been possible for the researchers to reach consensus and to develop a commonly accepted assessment tool.

Comprehension of project complexity and assessment of its level in a project is not necessarily translated as a solution for the problems that are induced by it, however it definitely is an extra advantage for the project manager. A lot of problems that emanate from complexity could have been mitigated or even avoided, if the factors that rendered a project complex and the risks that they induce, were fully comprehensible in order for a more appropriate management process to be established.

All the above mentioned concerns define the framework in which lies the importance of the present research. The aim of this study is the analysis and comprehension of the meaning of complexity in engineering projects through the identification of the factors that affects it and insert it in projects. Based on the identified factors a project complexity measurement / assessment model is going to be proposed. The following research questions will be addressed through this study:

- What are the factors that induce complexity in an engineering project?
- What could be a commonly accepted project complexity measurement model?
- The present research follows a five-phase approach attempting to confront the abovementioned problems and to answer the research queries proposing a new project complexity measurement tool. These stages are as follows:
- Literature review: Identification of the factors that affect complexity in an engineering project.
- Select – extract 21 main factors which constitute the integration and convergence of the existing theoretical and empirical approaches.
- Conduct a questionnaire survey in order to evaluate the importance of each factor in the increase of complexity in engineering projects.
- Statistical analysis of the results of the survey in order to end up to the minimum possible key factors that will constitute the main components of the proposed project complexity measurement model.
- Form a project complexity measurement model based on the main component – factors and multiple-criteria decision analysis methods.

2. Literature Review

2.1. In General

An extended literature review has been conducted in order to identify the existing project complexity definitions, to detect all the factors that have been documented by previous researches as the main contributors to the complexity of engineering projects and finally to analyze the way through which these factors affects complexity. The progress of the researchers' comprehension of project complexity's meaning is studied as well as the conceptual difference between complex and complicated. In addition, the aspects of uncertainty and risk in the light of project complexity are being analyzed. Finally, all the literature review's findings regarding the existing project complexity measurement or assessment tools are described, while their weaknesses and deficiencies are investigated in order to come to a conclusion as far as the minimum requirements of a potent complexity measurement model concerns.

2.2. The Concept of Project Complexity

Before any other analysis it is necessary to locate and identify the most commonly accepted definition of complexity. As it has previously been underlined there is no formally established definition for the term of complexity in engineering projects however one can use as the most salient of them the one given by [5] who taking into account the works of [2], [6], [7], and [8] proposed the following definition: *"Project complexity is the property of a project which makes it difficult to understand, foresee and keep under control its overall behavior, even when given reasonably complete information about the project system"*.

A common point of confusion trying to approach the concept of complexity is the differentiation between complex and complicated. Complicated is a system which is not simple however could be ultimately knowable. On the other hand, complex is a system which is not simple too but it could never be fully knowable as there are too many interacting variables [9]. Following the same approach Snowden and [10] define that in a complicated context there is at least one correct answer, while in a complex context the correct answers cannot be identified.

An important aspect of the concept of complexity in engineering projects is its relation with the conception of uncertainty and risk. The management of existing uncertainty and the risks that induces in engineering projects is of the utmost importance for a contemporary project manager. To that extend the relationship between complexity and uncertainty becomes essentially more crucial. Literature review proves that the relationship between complexity, project's risks and uncertainty is vague not only from an academic point of view but from the standpoint of the construction industry as well [1].

For some researchers uncertainty is a type or a dimension of complexity. This conception of uncertainty coincides with the complexity theory. Uncertainty according to that approach has to do both with the current and future status of every element of the project and with the way these elements interact between each other [10].

The vague nature of the relationship between uncertainty and complexity is underlined by the fact that there are completely contradictory approaches at the existing literature. In one of them complexity seems to be one of the main reasons of prediction incapacity in projects, especially when it has to do with predicting problems or potential failures. Hence, according to that approach uncertainty is one of the negative consequences of complexity [1].

At the other side of the spectrum there is the reverse assumption. According to Bosch-Rekveldt, Jongkind, Mooi, Bakkerand Verbraeck [11] in some cases it could be considered that complexity is caused by uncertainties. [12] agrees with that approach of uncertainty as a source of complexity. Their argumentation focuses on the fact that the number of a project's risks, as well as the probability and impact of them could contribute to the increase of complexity.

Finally, there is the opinion that uncertainty and complexity are two different and conceptually unconnected notions and any try to find a relationship between them adds more confusion to the researches [9]. One could be completely uncertain for a system or a context due to lack of knowledge but at the same time the system could be simple and clear [13].

2.3. Identification of Project Complexity Factors

The identification of project complexity factors is a prerequisite in order for a valid and reliable measurement model to be proposed. To that end, it is necessary to locate and record in an analytical way all the elements that induce complexity in an engineering project. The formation of the proposed measurement tool is going to be based on the assessment of these factors as the main criteria of project complexity.

Literature related to the identification of project complexity factors is extensive enough to be considered exhaustive. Within the framework of recent literature reviews a lot of researchers have done a detailed write down of these factors in order to categorize them. These categorizations contribute to the comprehension of the concept of project complexity and at the same time gives the ability to the project manager to focus on particular areas for a quick assessment of a project's complexity level.

The most important researches pertaining the identification and categorization of project complexity factors are presented hereunder.

TOE framework is one of the most significant literature researches about the project complexity factors and has been done by [14]. The researchers ended up to a total of 50 factors that were categorized under three main categories, Technological, Organizational and Environmental. On a lower level, the factors were further grouped into subcategories.

A very extensive recording of the elements that contribute to the complexity of project has been done by [15]. The researchers approached the idea of a project as a system and based on that located a total of 70 factors of project complexity. They were categorized on two levels.

Into the first level the categorization followed the approach of [2] who distinguishes two main segregations technological and organizational complexity. On the second level the grouping was done based on whether the complexity factor is relative with the concept of size, variety, interdependency and context.

A slightly different approach regarding the arrangement of complexity factors is the one proposed by [15]. In their research they locate and focus on elements of project complexity considering the distinction between the terms of dimension and severity. The term of dimension answers where the complexity comes from and the term of severity tell us to what extent it will be a problem. The researchers conducted an extended literature review resulting to 5 complexity dimensions (namely goals, means to achieve goals, number and interdependency of elements, timescale of project and environment – market, political regulatory) and 9 severity factors (namely difficulty, non-linearity, uncertainty, uniqueness, communication, context dependence, clarity, trust and capability).

In addition to these, a lot of other researches have been studied during this work, less broad than the above-mentioned but not of secondary importance. Within this context many additional factors influencing project complexity have been recorded by the analysis of the studies of [16], [3], [17] and [18].

The results of the above analytical literature exploration ended up to more than 200 factors that are related to the complexity of engineering project. For the identification of the most important of them a selection and aggregation process was carried out. In the frame of that process it was ascertained that many of them were repeated identically throughout different researches, other constituted a sub-factor of a general element that covered them from a conceptual point of view and finally some few of them were trivial aspects that could be neglected.

The whole selection and aggregation process converged to 21 factors as the main and most commonly accepted components that contribute to the complexity of engineering projects. These factors are recorded into Table 1 hereunder and constitute the conceptual convergence field of the literature review of existing researches pertaining the factors that affects project complexity.

Table 1. *Project complexity factors.*

	Complexity factors	Clarification
1	Total Cost of the project	Total cost needed for the completion of the project (material costs, human resources' cost, machinery's costs, equipments' cost, general expenses etc). In general, all the costs that may be required through the life cycle of the project.
2	Duration of the project	The anticipated / prospective duration of the project. The total time that is required for the completion of the project.
3	Size of human resources of the project	Number of the people working for the project. Personnel working for the completion of the project at all levels or phases.
4	Interdependence of human resources of the project	Interrelationship between people that work for the project. High demands for interactivities, communication and cooperation of the personnel of the project.
5	Number and variety of funding sources of the project	Number of variant funding sources and financing roots of the project.
6	Credibility of funding sources of the project	Availability and reliability of the necessary funds in order for the project to be concluded smoothly.
7	Number and variety of contract types of the project	Number of the required contracts. Variety of the contract types and procurement systems of the project. Suitability of contract types. Dependencies between the deliverables of various contracts of the project.
8	Number of stakeholders of the project	Number of involved stakeholders of the project (contractors, partners, subcontractors, users, suppliers, organizations, agencies etc).
9	Interdependence of stakeholders of the project	Stakeholders interrelation. Level of alignment of stakeholders' interests or level of conflict of interests. Diversity of stakeholders' perception regarding project's positive or negative outcome.
10	Technological demands of the project	High level of technological or construction difficulty. Technological challenges. Technological novelty, unknown, innovational technologies. Frequent technological changes that may render the project obsolete.
11	Environmental impacts and constraints of the project	Design or construction process of the project susceptible to environmental factors. High environmental / ecological footprint of the project. Need of special environmental management of the project.
12	Geographic dispersal of the project	Number of different / variant / concurrent construction sites, places, spaces where the project or part of it is conducted.
13	Organizational change required for the implementation of the project	Level of change that is required in the organizational structure of the enterprises, organizations, agencies that take part into the project in order for that to be implemented. Impacts in business processes. Organization shifts or transforms. Level of administrative or managerial overhaul due to the project.
14	Size of scope and number of deliverables of the project	Number and variety of activities, tasks and works of the project. Breadth of the scope. Number of variant parts, elements, components of the project. Variety of the deliverables.
15	Interdependence of activities of the project	Interrelations (technical or temporal) between the tasks / activities or among different parts or components of the project.
16	Ambiguity of project'sscope	Instability of requirements of the project. Specification's variance. Frequent changes of customer or customer's demands. Dynamic conditions throughout the project's life cycle.
17	Requirements and availability of resources of the project	High demands for resources (materials, services, machinery, equipment etc). Great variety / diversity of resources required for the project. Singularity of resources. Availability of the resources. High level of dependency on third-party suppliers.
18	Political and legislative context of the project	High level of political - governmental involvement in the project. Complicated existing legislative or institutional framework. Need for new legislation or for legal regulations in order for the project to be implemented.
19	Cultural and social factors of the project	Cultural differences of the human resources of the project. Cultural or social constraints due to the locality of the project. Cultural or social peculiarities, local identities and relevant factors that shall be taken into account for the implementation of the project.
20	Strategic importance of the project for the organization/enterprise	Significance of the project according to the strategy plan of the organization or the enterprise. Gravity of the project in the project portfolio of the organization/enterprise. Level of impact of a potential success or failure of the project to the organization/enterprise.
21	Interactionswithotherprojects	Interrelations with other (third-party's) projects. Influence (technical, temporal or financial) over or influenced by other (third-party's) projects.

3. Questionnaire Survey – Statistical Analysis

3.1. Questionnaire Survey Research

The abovementioned 21 complexity factors were posed for evaluation of their importance in the increase of complexity in engineering projects. The survey was carried out in order to identify the key parameters that affect the degree of project complexity and to limit as far as possible the provided variables that will be used in order to form a project complexity measurement model.

An online survey method was chosen due to the limited time available and the low cost.The participants were asked to evaluate the importance of each factor based on their experience and understanding using a 5 level Likert scale. The conceptual difference between each grade at the Likert scale was considered equal. Thus the available answers for the evaluation of importance of each complexity variable were as shown at Table 2.

Table 2. *5-level Likert scale answers.*

	Likert Scale
1	Not Important
2	Slightly Important
3	Moderately Important
4	Very Important
5	Extremely Important

The results of the research concluded to the project complexity factors shown in Table 3, ranked according to their significance based on the mean values of the participants' answers.

Table 3. *Questionnaire results – Project complexity factors ranked according to significance.*

	Complexity factors	Mean value	Std. Deviation
1	Ambiguity of project's scope	4.36	0.841
2	Technological demands of the project	4.04	0.830
3	Interdependence of activities of the project	4.04	0.894
4	Interdependence of human resources of the project	4.02	0.863
5	Requirements and availability of resources of the project	4.00	0.953
6	Total Cost of the project	3.95	0.980
7	Duration of the project	3.89	0.824
8	Size of human resources of the project	3.88	0.854
9	Credibility of funding sources of the project	3.84	1.125
10	Political and legislative context of the project	3.80	1.197
11	Number of stakeholders of the project	3.71	0.948
12	Interdependence of stakeholders of the project	3.63	1.019
13	Number and variety of contract types of the project	3.61	0.888
14	Size of scope and number of deliverables of the project	3.59	0.890
15	Environmental impacts and constraints of the project	3.52	0.934
16	Strategic importance of the project for the organization/enterprise	3.52	1.062
17	Organizational change required for the implementation of the project	3.48	1.079
18	Interactions with other projects	3.36	0.980
19	Geographic dispersal of the project	3.29	1.039
20	Number and variety of funding sources of the project	3.21	1.140
21	Cultural and social factors of the project	3.13	1.129

3.2. Statistical Analysis – Factor Analysis

The next step consisted of the appropriate exploitation of the research results in order to form and propose a new complexity measurement model. Within that context and for the purpose of identifying and understanding the relationships between each complexity factor pair, a correlation analysis using Pearson's correlation coefficient was conducted. Primarily, a relatively potent positive correlation was detected.

From the beginning of the research the main goal was the reduction of the complexity factors that are going to be taken into account to the formation of the complexity measurement tool in order for this to be simple, user-friendly and effective. For this reason and in order to locate the complexity factors that represent in the most appropriate way the main components among the group of complexity variables, a Factor Analysis was conducted using the SPSS software package.

The methodology of Factor Analysis was considered as the most suitable inferential statistical tool within the research framework of the present study as the main components that are rendered as a result maintain to a great extent the information that existed in the data of the initial variables. The main purpose of factor analysis is the data reduction. The principal components method finds a linear combination of variables (namely a component) that accounts for as much variation in the original variables as possible. Then it finds another component that accounts for as much as possible of the remaining variation and it is not correlated with the previous component and so forth. As a result, a few components will account for the majority of the variation and these components can be used to replace the original variables.

In order to ensure that the data of the present study are adequately suitable for the implementation of factor analysis it is necessary to perform some tests for its “factorability”. These tests are Bartlett’s test of sphericity and the Kaiser – Meyer – Olkin (KMO) measure of sampling adequacy. Bartlett’s test of sphericity tests the hypothesis that our correlation matrix is an identity matrix which would illustrate that our variables are unrelated and as a result unsuitable for structure detection. Values of the significance level less than 0.05 indicate that factor analysis would be useful implemented on our data. The KMO measure of sampling adequacy is a statistic which indicated the proportion of variance in our variables that might be caused by underlying factors. High values denote that in general factor analysis would be useful with our data, while values less than 0.5 mean actually that there is no advantageous reason to act so.

Executing these tests to the data of the present research produced the results of Table 4 which generally entail suitability to conduct factor analysis. However, it could be referred that a higher value at KMO measure (near to 0.800) would probably product more coherent results after performing factor analysis.

Table 4. *KMO and Bartlett's tests.*

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		.640
Bartletts's Test of Sphericity	Approx. Chi-Square	433.327
	df	210
	Sig.	.000

First step at implementing factor analysis on the data of the research is the calculation of extraction communalities. Communalities illustrate the amount of variance in each variable that is accounted for. Initial communalities are estimates of the variances in each variable accounted for by all components or factors and in the case of principal components extraction is always equal to 1. Extraction communalities estimate the variance in each variable accounted for by the components.

Taking these into consideration the total variance explained table is calculated in which an initial solution is firstly depicted where there are as many components as variables and the sum of the eigenvalues equals the number of components. Applying the Kaizer criterion according to which only eigenvalues greater than 1 are extracted, it finally ends up to 7 extracted components. Table 5 shows the 7 extracted components which explain nearly 68.9% of the variability in the original 21 variables. Thus, by using only these 7 components a considerable reduction of the volume of the initial data is succeed. In particular, although it results to the usage of only 33% (7 out of the 21) of the initial variables it succeeds to explain almost 70% of the total information.

Table 5. *Extraction sums of squared loadings.*

Component	Eigenvalue	% of Variance	Cumulative %
1	5.464	26.020	26.020
2	2.301	10.957	36.977
3	1.589	7.566	44.544
4	1.507	7.174	51.718
5	1.353	6.445	58.163
6	1.234	5.874	64.037
7	1.022	4.867	68.904

The scree plot depicted at Figure 1 helps to understand how it ended up to 7 as the optimal number of components. The eigenvalue of these 7 components is over 1 and actually are these that belongs to the steep slope of the curve. The components on the shallow slope do not contribute substantially to the solution.

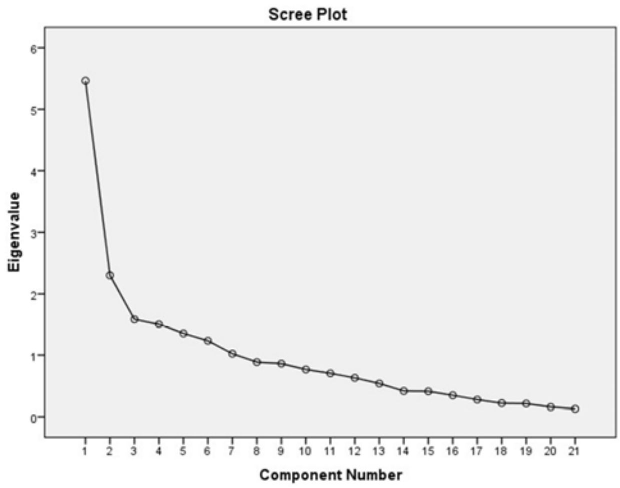

Figure 1. *Scree plot.*

Finally, in order to determine the factor that represents in the most sufficient way each one of the 7 components the rotated component matrix is calculated. In the rotated component matrix, a coefficient is calculated for each variable and each component. Upon the implementation on the data of the research 7 key factors were identified that represent the 7 main components among complexity variables. These 7 key factors portray almost the 70% of the total variance of the initial 21 complexity factors and they are as follows, ranked according to their significance level resulted from the research assessment:

- Requirements and availability of resources of the project (C1)

- Duration of the project (C2)
- Size of human resources of the project (C3)
- Political and legislative context of the project (C4)
- Number of stakeholders of the project (C5)
- Interactions with other projects (C6)
- Number and variety of funding resources of the project (C7)

The resulting 7 factors - variables are representative of, and can be used in place of, the 21 original variables with only a 30% loss of information.

4. Results – Exploiting Factor Analysis Outcomes

In order to use advantageously the beneficial reduction of the conceptual range of complexity that was achieved by the usage of factor analysis, a suitable method has to be used that could integrate adequately the importance of these 7 key factors of engineering projects complexity.

[15] have conducted an analytical literature review in order to define the requirements that a method has to meet in order for it to be used as a good tool for project complexity evaluation. They evaluated many multi-criteria decision analysis methodologies based on criteria set in light of meeting these requirements and ended up to use the Analytical Hierarchy Process. Using this evaluation ranking for the present research the usage of a simplified method of multiple-criteria decision analysis, namely Single Multi Attribute Rating Technique Exploiting Ranking – SMARTER has been decided as one of the most suitable for the exploitation of the results achieved by the factor analysis.

The Single Multi Attribute Rating Technique (SMART) is a simple method of the Multi Attribute Utility Theory. The SMART technique is based on a linear additive model. This means that an overall value of a given alternative is calculated as the total sum of the performance score (value) of each criterion (attribute) multiplied with the weight of that criterion [15]. [8] recognized that the assessment of value functions and swing weights in SMART was the most demanding and troublesome task about which the decision-makers most of the times did not feel confident. To that end they suggested a simplified form of SMART named SMARTER (SMART exploiting ranks) [19], [22]. Within that framework [19] supported that generated weights may be more precise than those given by the decision-makers especially if one takes into account the fact that the decision-makers do not feel comfortable enough with this process.

A number of methods have been developed in order to translate the ranking of the criteria into surrogate weights representing a resemblance of the “true” weights, approximating them as much as possible. Following a comparison of them conducted by [21] the Rank Order Distribution (ROD) weight approximation method has selected as the most appropriate for the present research. Values for ROD generated weights taking into account 7 attributes – criteria are shown at Table 6.

Table 6. *ROD generated weights for 7 criteria.*

Rank order of criterion	Weight of criterion
1	0.2590
2	0.2174
3	0.1781
4	0.1406
5	0.1038
6	0.0679
7	0.0334

These weights corresponded to each one of the 7 key component complexity factors located by the factor analysis process and ranked according to their significance rate resulted from the research assessment, give the following criteria and weights, on which the complexity measurement tool is going to be formed:

- Requirements and availability of resources of the project (C1): wc1=0.2590
- Duration of the project (C2): wc2=0.2174
- Size of human resources of the project (C3): wc3=0.1781
- Political and legislative context of the project (C4): wc4=0.1406
- Number of stakeholders of the project (C5): wc5=0.1038
- Interactions with other projects (C6): wc6=0.0679
- Number and variety of funding resources of the project (C7): wc7=0.0334

5. Conclusions – Proposed Project Complexity Measurement tool

Following the abovementioned analysis, a practical and approachable model of project complexity measurement is introduced, named Complexity Level Indicator (CLI).

CLI uses Rank Order Distribution (ROD) weights over the 7 identified key factors which comprise the decision criteria (C1 to C7). The following formula is applied:

$$CLI = \sum_{i=1}^{7}\left(w_{C_i} * S_{C_i}\right) \quad (1)$$

where:

w_{Ci} is the ROD weight for criterion Ci and

S_{Ci} is the grade (values from 1 to 10) ascribed to the project by the tool user as far as criterion Ci concerns. High grade of the project regarding criterion Ci means high level of the in question complexity factor in the particular project.

CLI results values from 1 to 10, while high values denote high level of project complexity and respectively low CLI values mean low project complexity level.

Finally, it is highlighted that the user of the method could in any case modify the criteria rank, adopting the method to potential peculiarities of the project (s) under assessment. This adjustment capability transfuses to him extra flexibility concerning the complexity assessment of each project.

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