Identifying required project managers' core competencies in complex product systems using project complexity assessment: A case study in Iran's oil and gas R&D projects

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Abstract. The nature and high sensitivity of complex products and development projects lead to increased complexity at operational and organizational levels requiring particular types of organizing & management styles. Identifying the key competencies required for project managers, especially those managing complex research and development (R&D) projects in the oil and gas industry, can increase the chance of project success. The main objective of this research is to identify the key competencies required for managing complex products and systems (CoPS) in R&D projects carried out in Iran's oil and gas industry. The Delphi- fuzzy approach is used to develop an effective measurement model based on group decision-making methods and fuzzy inference systems. The results and analyses of the model are used to determine the key competencies needed in the studied organization. The results demonstrate that risk management, system integration, and personal abilities with competency importance factors of 1.7, 1.6, and 1.6 respectively, are more important than other competencies while dealing with complexity in the projects studied.

KEYWORDS: Complex products and systems; Competency; Research and development projects; Oil and gas industry; Project complexity management.

1. Introduction

Simon [1] was one of the first researchers who defined a complex system consisting of numerous complicated and interconnected components. Furthermore, he emphasizes that in these systems, the importance of the whole system outweighs the importance of its components. Most researchers define complexity from their perspectives and areas of expertise. Hence no theoretical consensus has yet been reached on its definition [2]. As a

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result, complexity has been identified as a common topic in project management research papers [3].

Simon [1] emphasizes that the degree of complexity or simplicity of a structure is heavily dependent on the approach used to describe it. Given this judgmental position and the different individual viewpoints, the challenge of quantifying complexity seemed unanswered until it was addressed in the literature [4, 5]. In the last decade, many studies presented methods to measure and quantify project complexity to better understand and evaluate project complexity [6-12]. CoPS projects, which are high value-added products with high technical complexity, can be classified as complex projects with significant dynamics, influenced by various forms of innovation and a high degree of customization [13]. The complexity of these initiatives is one of the leading causes of project problems, impairments, and failures [14, 15]. A practical method to manage complexity and its possible negative consequences in this type of project are to create competency frameworks for project managers, which are widely recognized through research articles and some standardized frameworks. [5, 16-18]

In addition, due to the high level of dynamics and differentiation in CoPS projects, a tailored approach is needed to identify the required core competencies. To achieve this goal, a metric that provides a threshold for project complexity is required. The main problem here is that without defining a non-binary measure of project complexity, it is impossible to create a tailored competency map in terms of complexity level and its main contributors, which have been largely ignored in the field of complex project management [5, 19] and can be considered as the main research gap. In the oil and gas industry, research and development projects are classified as complex products and systems (CoPS), and the project-oriented organizational structure is one of the recognized ideal and best solutions for managing such projects. Brady and Davies [20] investigated the methods of managing the structural and dynamic complexity of two successful mega projects. Their research demonstrated that several similar criteria were employed in managing complexity, which resulted in the projects being completed on time and within budget. Strong client leadership and capabilities, collaborative behaviors, adaptability, incorporation of innovative approaches and digital technologies, and focus on a results-oriented approach were the most notable factors.

Therefore, the primary benefit of this study is to provide a method to capture the competencies of project managers in the research and development department of the oil and gas industry, using a project complexity assessment method to make projects “complexity capable”.

The main contribution of this study is to establish a link between competency mapping and complexity analysis in the studied CoPS projects to improve project performance and success factors, which is ignored by the literature. Hence, an effective model for quantifying project complexity based on group decision-making methods and fuzzy inference systems is presented, which is based on the research problem and uses the fuzzy Delphi approach. The results are used to identify the most critical competencies needed by project managers.

2. Literature review

This section first discusses the concepts and framework of project complexity and the factors that influence it. It then discusses the key competencies required for complex projects as mentioned in the literature.

2.1. Project complexity

Simon was one of the first researchers to define a complex system as one that consists of numerous components that interact in ways that are not simple [1]. Complexity science is a popular branch of study that combines a variety of interdisciplinary sciences [5]. Some scholars (e.g., Rosenhead) are skeptical of the interdisciplinary applications of complexity theory [21]. Complexity theory has evolved from chaos theory and has been discussed in scientific circles since 1800. Before the 1990s, there were few research articles on project complexity and few academic papers and dissertations on quantifying complexity and defining indices in the construction industry [22, 23]. Turner and Cochrane [24] published an article named "the goals and methods matrix" which established four categories of projects based on the clarity or ambiguity of expected goal definitions and the methods used to achieve them. Another pioneering study on project complexity is the work of Baccarini [6], which focuses directly on the concept of project complexity and the related literature. In addition to a brief review of the literature on this topic up to 1996, he described project complexity in terms of differentiation and interdependency. Terry Williams presented a paper from the introductory session of the seminar on "managing and modeling complex projects" only three months after Baccarini's article was presented, in which he talked about complex projects and the need for a new paradigm for their management [25]. Some researchers [26, 27] studied the uncertainty structure to investigate the relationship between product development characteristics and project outcomes. They studied product development projects from the perspective of technological innovation and project complexity. In 2006, an article entitled "measuring project complexity: a tool for a project manager" was presented that developed a model and indicator for measuring project complexity using Shannon's information theory and the concept of system entropy (information required to define a system) [7].

After an overview of the concepts of project complexity, Vidal et al. [8] analyzed the existing models and metrics in this area. In another study, Vidal and Marle [4] discussed the factors and drivers of project complexity, shown in Fig. 1. Following their 2008 work on understanding complexity, Vidal et al. [9] focused on measuring and quantifying project complexity. In their paper, they used the AHP technique to measure project complexity using a multi-criteria decision-making approach. Bosch-Rekveldt et al. [11] proposed a framework for project complexity in large engineering projects in the same year. They emphasized the significance of complexity in project management research by evaluating the large number of studies published in recent years that focused on the project. Their paper investigates all aspects of project complexity by classifying it into three categories: technical, organizational, and environmental. Project complexity is assessed at the end of the planning phase and before the initiation phase.

{Please insert Fig. 1 about here}.

The complexity and dynamics of software projects have a negative impact on their success. The use of waterfall or agile project management for software development has sparked a debate among researchers about which method better manages the complexity and dynamics of software projects without reaching a definitive agreement. This issue was explored by analyzing data from a survey of software development professionals. It was concluded that managing dynamics is critical to project success and that no strategy is better suited to minimizing dynamics than the agile project management approach [28]. Another comprehensive study on quantifying and managing project complexity was conducted between 2012 and 2015 at the University of Texas at Austin in collaboration with the American Society for Construction Management. Articles on this topic were published in 2016 [29-31]. Zhu and Mostafavi [32] also used interviews with 19 experienced construction project managers to develop an integrated methodology for evaluating project performance while taking complexity into account.

Kiridena and Sense [33] created a system for categorizing project complexity. They distinguished three categories of complexity. The first category is complicated systems, which represent structural complexity. Obscurity, ambiguity, unpredictability, constraints, and intricacy are all characteristics of complicated systems. The category of complexity is complex systems that consist of nonlinear interactions between parts that lead to emergent behavior. Complex adaptive systems, the third category of complexity, represent an adaptation to the environment leading to evolution and self-organization. Several studies in the literature propose competency-based assignments for project teams [34]. These publications ignored the influence of project complexity and unique characteristics in defining and prioritizing the required key competencies. Compared to previous studies on this topic, this paper proposes a unique and practical approach to complexity measurement based on intelligent fuzzy systems and fuzzy decision-making techniques. In addition to the high accuracy of the proposed technique, using a fuzzy Delphi approach for data collection is also a less expensive and time-consuming strategy that simplifies the application of the model. Finally, the main innovation of this research is the presentation of a competency mapping framework based on the required key competencies in complex products and systems using the proposed complexity measurement approach.

2.2. CoPS Projects

With the massive changes in the market and technology in the last two decades, advanced industrialized countries have shifted to the production and innovation of CoPS, which can be defined as technology-dependent and proprietary capital goods, systems, networks, control units, software packages, structures, and costly services [35-37]. The nature of CoPS can lead to a high level of complexity that requires unique management and organization [38]. Zhang pioneered the concept of CoPS in research on the innovation of aircraft and telecommunications equipment. For the management of CoPS projects, researchers in this field have mainly referred to project-oriented organizations and, in some instances, matrix organizations [36]. Recent research in the field of innovation has recognized the use of new leadership behaviors and alternative organizational structures in dealing with the increasing complexity of production, communication, and technology [39, 40]. Project-oriented organizations design their structure and capabilities to meet the project's needs. Although project-oriented organizations are not ideal for mass production, large manufacturing companies use project-based structures for complex activities such as product research and development [41].

From the literature review, most studies emphasize the compatibility of project-based structure with CoPS project management. According to Penrose and Penrose [42], the pioneer of the resource-based approach, successful organizations consolidate their business foundation through the specialized use of physical and human resources. In a conceptual framework, Chandler examines how organizational competencies are positioned at the strategic and operational levels of the hierarchy. Reviewing related research on organizational capabilities and competencies that impact complex product and system projects identified the most important factors [43]. One area that has received little attention is the evaluation and analysis of the complexity of R&D projects in the oil and gas industry. Given the importance of this issue and its impact on the success of the types of projects mentioned above, and after identifying the key complexity drivers through a survey and literature review, the required organizational competencies are identified and prioritized based on the complexity drivers.

3. Presented framework to measure project complexity

In this study and its recommended framework, the factors that influence project complexity are classified into two structural and dynamic dimensions, and two project and organizational levels. Fig. 2 shows a schematic representation of this framework.

{Please insert Fig. 2 about here}.

The factors that influence project complexity can therefore be divided into general categories. Table 1 summarizes the factors that influence project complexity based on the description, literature review, and proposed model for classifying project complexity drivers. To create this table and identify the key contributing factors affecting project complexity drivers, numerous articles were reviewed [5, 39, 43-46]; however, the most important articles were in [11] and [47].

{Please insert Table 1 about here}.

4. Proposed model to measure project complexity

To find projects with a higher degree of complexity, compare the complexity of some candidate projects using specific criteria in this section. This problem can be transformed into a multi-criteria decision-making problem where the alternatives are the candidate projects, and the criteria are the project complexity drivers. Given the inherent ambiguity in the concept of project complexity and the uncertainties in its drivers, the input data for the factors affecting complexity drivers can be quantified using fuzzy numbers as a feasible method [48].

4.1. Shannon entropy method for calculating criteria weight

The procedures for calculating the weights of the criteria using the Shannon entropy method are described as follows:

Step 1) In this step, expert opinions are collected based on defined linguistic variables. The initial decision matrix is created by defining the corresponding triangular fuzzy number for each of these variables [49]. It is worthwhile to mention that, the initial decision matrix is an *m*n* matrix in which there are *m* alternatives and *n* criteria.

Step 2) Defuzzification of the input data is the second step. In this step, the center of area method (COA) is used to defuzzify the fuzzy numbers:

$$x_{ij} = \frac{[(u_{ij} - l_{ij}) + (m_{ij} - l_{ij})]}{3} + l_{ij} \qquad (1)$$

Step 3) Normalization of the defuzzified matrix. The TOPSIS method uses a vector-based method to normalize the decision matrix using by:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{1}^{m} x_{ij}^{2}}} \qquad (2)$$

Step 4) Calculation of the entropy method according to Section 2.4.2 and the weighting of each criterion. In this step, the normalized matrix elements of the previous step are multiplied by their natural logarithm, and by calculating the entropy index for each criterion (*Ej*), the corresponding weight is also calculated.

4.2. Fuzzy TOPSIS method for ranking alternatives

At this stage, the fuzzy TOPSIS method is used to rank the alternatives. The steps of this method are as follows:

Step 1) The fuzzy decision matrix, which is the average of the experts' opinions, is formed.

Step 2) Using the mentioned normalization method, a fuzzy normalized matrix is created by the fuzzy TOPSIS method.

Step 3) By multiplying the row matrix of weights in the fuzzy normalized decision matrix, the weighted normalized matrix will be obtained.

Step 4) By selecting the maximum and minimum elements of each column, the positive and negative ideal fuzzy solutions, respectively, will be created.

Step 5) The distance matrix of positive and negative ideal solutions is calculated. In this step, according to the results of steps three and four, the sum of the distances of each alternative to the positive and negative ideal solutions is calculated.

Step 6) The index of the TOPSIS method for the alternatives is calculated.

After calculating the two matrices of the previous step and calculating the last column in both matrices, the relative distance index of the negative ideal solution is calculated by the following equation for each option.

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \qquad (3)$$

In this research, a fuzzy inference system is used as an expert system to calculate the degree of project complexity as a fuzzy rule-based system (FRBS). A bi-level fuzzy inference system was developed to calculate the overall degree of project complexity after calculating the project complexity in four categories of the proposed framework. Fig. 3 shows a schematic overview of the considered system.

{Please insert Fig. 3 about here}.

The number of rules for each of these systems depends on the type of input variables defined at each stage and the number of linguistic variables associated with them. The efficiency and performance of this method are evaluated in the case study section using numerical examples. Also, the following network framework is presented to identify and prioritize the key competencies required in the studied projects based on the literature review and the identified key complexity and competency criteria (Fig. 4).

{Please insert Fig. 4 about here}.

5. Case study

The selected case study is a project-based research organization in the oil and gas industry that conducts research and development projects. Four of the organization's projects were studied, all of which deal with the design and creation of complex products and systems in the oil and gas industry. The project team includes knowledge workers who should carry out the work related to research, engineering, and design. Due to confidentiality concerns, it is not possible to provide more details about these projects.

As an example, consider the following steps for one of these drive groups (structural project level):

Step 1) The fuzzy decision matrix for the first set of drivers is obtained and normalized by obtaining the input from experts using the fuzzy Delphi method and calculating the average of the opinions (according to the method explained in Step 3 of Section 4.1). Table 2 shows the normalized matrix.

{Please insert Table 2 about here}.

Step 2) To calculate the weights of the criteria (here the complexity drivers), first convert the above fuzzy matrix elements into definite numbers using the Center of Area method (COA) and the following relationship:

$$x_{ij} = \frac{[(u_{ij} - l_{ij}) + (m_{ij} - l_{ij})]}{3} + l_{ij} \qquad (4)$$

Step 3) After calculating the weights of the criteria and the normalized matrix, multiply the two matrices above to generate the weighted normalized fuzzy matrix.

Step 4) Table 3 shows the positive and negative ideal fuzzy solutions for the weighted normalized matrix generated in the previous step.

{Please insert Table 3 about here}.

Step 5) The weighted normalized fuzzy matrix is used in this step to calculate the distance between the A^+ and A^- matrices. Table 4 shows the amount of these distances for each project and their *CCi* index. As indicated in the table, by calculating the *CCi* index for each project, a complexity index is calculated for each set of drivers. Fig. 5 shows the complexity of the projects considered for the project-specific set of structural drivers.

{Please insert Table 4 about here}.
{Please insert Fig. 5 about here}.

Similarly, the six steps described above apply to the other three categories of drivers, providing results for each section. The input and output variables, as well as their membership functions and if-then rules, must be obtained from experts to create a fuzzy inference system. The inference system in this research is developed in two general stages, as shown in Fig. 3. The mentioned inference systems are designed by using a fuzzy toolbox in the MATLAB program. In the next session, the specifications of the developed systems and their results are given.

5.1. Two designed inference systems in Stage 1

The two input variables are shown below, along with their determined membership function. Fig. 6 also shows the project-level complexity as the output variable and the established if-then rules of the FIS for this step. The major components of this system are now identified, and it is ready to be used. Fig. 7 shows the output of the above system in the interface view.

{Please insert Fig. 6 about here}.
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5.2. Designed inference system in Stage 2

In this step, a fuzzy inference system is created to achieve the ultimate goal of determining the overall complexity of the project. This system's input variables are the project-level and organizational-level complexity, respectively. The output variable is also the level of complexity of each project for which the five levels of Gaussian-type linguistic variables are considered. Fig. 8 shows the overall complexity of this sample project in the rule viewer as an example. As a result, the overall complexity of each project is calculated using the two steps mentioned above and the proposed inference systems.

{Please insert Fig. 8 about here}.

6. Discussion

In this study, the overall complexity of four projects which are related to the design and development of complex products and systems in the oil and gas industry are calculated using the proposed calculation framework and the results are shown in Fig. 9.

{Please insert Fig. 9 about here}.

By analyzing the results and considering the number of impacts of each of the drivers, the most important individual and organizational competencies are identified and ranked. Based on the network framework provided and the relationships between the complexity drivers and required competencies, the most important competencies are determined in order of priority as presented in Fig. 10.

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The results obtained regarding the complexity of the projects and the competencies required for project managers have been determined by subject expert matters. According to the experience and knowledge that these experts have about the investigated projects, they confirmed the results of the model.

This study is useful for measuring the project complexity and managerial effort can be adjusted accordingly for better management of CoPS. There are some practical implications for this developed approach and the obtained results. The competencies and their ranking can help companies in recruitment, and educating their employees to have competencies to better manage their complex products and systems. Also, this study provides a novel approach to measuring the complexity of projects which can be incorporated to make better decisions for project portfolio selection based on the complexity indicator.

7. Conclusion and future research

In this research, concepts, and definitions, common frameworks, and the most critical factors impacting project complexity were identified after reviewing the literature on the subject of project complexity and key competencies required for the types of projects under consideration (CoPS). After categorizing the identified drivers, a measurement model was developed to create a quantitative index of project complexity in each of the driver categories. Multicriteria decision-making methods and four projects from a project-oriented company were used as case studies. After developing a customized framework for this model, complexity was measured for four projects using the proposed measurement model. The overall score was calculated using fuzzy inference methods since giving an overall score for the complexity of the projects based on the identified indicators requires expert analysis and judgment. In conclusion, the main results of this paper are as follows:

- After calculating the overall score, a framework was proposed to identify the key competencies required to manage complexity and related factors at the project and organizational levels.
- The results indicate that risk management competencies, system integration, and individual abilities (e.g., leadership and communication skills) are more important than other factors for managing and dealing with complexity in the considered projects and that the studied project-oriented organization should focus more on these competencies and their development.

- In summary, in project-oriented organizations, appropriate measures can be taken to better manage and control project complexity and the resulting negative impact on performance by identifying and quantifying the drivers of complexity. This approach was also used in this research for projects focused on organizational and individual competencies and their management.

The following recommendations can be used in future studies:

- This paper considers complexities in the oil and gas industry. Competencies to manage CoPS in other industries such as defense, construction and IT can be examined for future studies.
- Researchers might also investigate if these competencies can be sustained over time and how to improve these competencies to better manage complex products and systems.
- In this research, project complexity is assessed in the planning phase. Future works can focus on project complexity assessment in different project phases such as initiation and even in the execution phase, in case of project manager change.
- Future studies can build a link between the results of this work and project manager selection problems when there are some candidates for this critical role.

References

1. Simon, H.A., "*The sciences of the artificial*", 1969.

2. Corning, P.A. "The synergism hypothesis: On the concept of synergy and its role in the evolution of complex systems", *Journal of Social and Evolutionary Systems*, **21**(2), pp. 133-172 (1998).

3. Cicmil, S., Williams, T., Thomas, J. et al., "Rethinking project management: Researching the actuality of projects", *International Journal of Project Management*, **24**(8), pp. 675-686 (2006).

4. Vidal, L.A. and Marle, F. "Understanding project complexity: Implications on project management", *Kybernetes*, **37**(8), pp. 1094-1110 (2008).

5. Lee, C.Y., Chong, H.Y., Liao, P. et al. "Critical review of social network analysis applications in complex project management." *Journal of Management in Engineering* **34**(2), (2018).

6. Baccarini, D. "The concept of project complexity - A review", *International Journal of Project Management*, **14**(4), pp. 201-204 (1996).

7. Sinha, S., Kumar, B. and Thomson, A. "Measuring project complexity: a project manager's tool", A*rchitectural Engineering and Design Management*, **2**(3), pp. 187-202 (2006).

8. Vidal, L.-A., Marle, F. and Bocquet, J.-C. "Modelling project complexity", in: *Proceedings of the 16th International Conference on Engineering Design (ICED)*, Paris, France, pp. 28-31 (2007).

9. Vidal, L.-A., Marle, F. and Bocquet, J.-C. "Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects", *Expert Systems with Applications*, **38**(5), pp. 5388-5405 (2011).

10. Vidal, L.-A., Marle, F. and Bocquet, J.-C. "Measuring project complexity using the Analytic Hierarchy Process", *International Journal of Project Management*, **29**(6), pp. 718-727 (2011).

11. Bosch-Rekveldt, M., Jongkind, Y., Mooi, H., et al. "Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework", *International Journal of Project Management*, **29**(6), pp. 728-739 (2011).

12. Dao, Bac, Sharareh Kermanshachi, Jennifer Shane, et al. "Developing a logistic regression model to measure project complexity." *Architectural Engineering and Design Management*, **18**(3), pp. 226-240 (2022).

13. Roehrich, J.K., Davies, A., Frederiksen, L. et al. "Management innovation in complex products and systems: The case of integrated project teams." *Industrial Marketing Management*, **79**, pp. 84-93 (2019).

14. Bjorvatn, T. and Wald, A. "Project complexity and team-level absorptive capacity as drivers of project management performance." *International Journal of Project Management*, **36**(6), pp. 876-888 (2018).

15. Shahhossein, V., Afshar, M.R. and Amiri, O. "The root causes of construction project failure", Scientia Iranica, **25**(1), pp. 93-108 (2018).

16. Davies, A., Dodgson, M. and Gann, D. "Dynamic capabilities in complex projects: The case of London Heathrow Terminal 5", *Project Management Journal*, **47**(2), pp. 26-46 (2016).

17. Damayanti, R., Hartono, B. and Wijaya, A. "Leadership competency for megaproject's complexity management: A conceptual study", *International Journal of Innovation, Management and Technology*, **12**(4), pp. 68-74 (2021).

18. de Rezende, L.B., Paul Blackwell, P., Denicol, J., et al. "Main competencies to manage complex defence projects", *Project Leadership and Society*, **2**, Aricle No. 100014 (2021).

19. Harris, R. and Short, T. "*Workforce development: Perspectives and Issues*", Springer, N. Y. (2014).

20. Brady, T. and Davies, A. "Managing structural and dynamic complexity: A tale of two projects", *Project Management Journal*, **45**(4), pp. 21-38 (2014).

21. Rosenhead, J., "Complexity theory and management practice", *Operational Research working papers (LSEOR 98.25)*, Department of Operational Research, London School of Economics and Political Science, London, UK (1998).

22. Bennett, J. and Fine, B. "Measurement of complexity in construction projects", *Final Report of SERC Project GR/A/1342.4*, Department of Construction Management, University of Reading (1980).

23. Gidado, K., "Numerical index of complexity in building construction to its effect on production time", University of Brighton, Brighton, UK (1993).

24. Turner, J.R. and Cochrane, R.A. "Goals-and-methods matrix: coping with projects with ill defined goals and/or methods of achieving them", *International Journal of Project Management*, **11**(2), pp. 93-102 (1993).

25. Williams, T.M. "The need for new paradigms for complex projects", *International Journal of Project Management*, **17**(5), pp. 269-273 (1999).

26. Stock, G.N., Tsai, J.C.A., Jiang, J.J., et al. "Coping with uncertainty: Knowledge sharing in new product development projects", *International Journal of Project Management*, **39**(1), pp. 59-70 (2021).

27. Burton, N. and Galvin, P. "When do product architectures mirror organisational architectures? The combined role of product complexity and the rate of technological change", *Technology Analysis & Strategic Management*, **30**(9), pp. 1057-1069 (2018).

28. Butler, C.W., Vijayasarathy, L.R. and Roberts, N. "Managing software development projects for success: Aligning plan-and agility-based approaches to project complexity and project dynamism", *Project Management Journal*, **51**(3), pp. 262-277 (2020).

29. Dao, B., Kermanshachi, S., Shane, J., et al. "Identifying and measuring project complexity", *Procedia Engineering*, **145**, pp. 476-482 (2016).

30. Dao, B., Kermanshachi, S., Shane, J. and Anderson, S. "Project complexity assessment and management tool", *Procedia Engineering*, **145**, pp. 491-496 (2016).

31. Kermanshachi, S., Dao, B., Shane, J., et al. "Project complexity indicators and management strategies - A Delphi study", *Procedia Engineering*, **145**, pp. 587-594 (2016).

32. Zhu, J. and Mostafavi, A. "Discovering complexity and emergent properties in project systems: A new approach to understanding project performance", *International Journal of Project Management*, **35**(1), pp. 1-12 (2017).

33. Kiridena, S. and Sense, A. "Profiling project complexity: Insights from complexity science and project management literature", *Project Management Journal*, **47**(6), pp. 56-74 (2016).

34. Shahhosseini, V. and Sebt, M. "Competency-based selection and assignment of human resources to construction projects", *Scientia Iranica*, **18**(2), pp. 163-180 (2011).

35. Safdari Ranjbar, M., Ghazinoori, S. and Manteghi, M. "Evolution of Iran's gas turbine sectoral innovation system as a complex product system (CoPS)", *African Journal of Science, Technology, Innovation and Development*, **14**(4), pp. 1102-1116 (2022).

36. Zhang, L. and Hu. H. "Using complex products and systems in the pharmaceutical innovation: Case study of R&D project in pharmaceutical industry", in: *Proceedings of the 2011 IEEE International Summer Conference of Asia Pacific Business Innovation and Technology Management*, IEEE (2011).

37. Safdari Ranjbar, M., Park, T.-Y. and Kiamehr, M. "What happened to complex product systems literature over the last two decades: Progresses so far and path ahead", *Technology Analysis & Strategic Management*, **30**(8), pp. 948-966 (2018).

38. Hardstone, G. "Capabilities, structures and strategies re-examined: incumbent firms and the emergence of complex product systems (CoPS) in mature industries", *Technology Analysis & Strategic Management*, **16**(2), pp. 173-196 (2004).

39. Princes, E. and Said, A. "The impacts of project complexity, trust in leader, performance readiness and situational leadership on financial sustainability" *International Journal of Managing Projects in Business*, (2022).

40. Ram, J. and Ronggui, D. "Research and development projects: An empirical investigation of project managers' traits", *International Journal of Managing Projects in Business*, *11*(3), pp. 913-934 (2018).

41. Mehr, M.R., Rashed, S.A.M., Lueder, A., et al. "An Approach to Capture, Evaluate and Handle Complexity of Engineering Change Occurrences in New Product Development", *International Journal of Industrial and Manufacturing Engineering*, 15(9), pp. 400-408 (2021).

42. Penrose, E. and Penrose, E.T. "*The theory of the growth of the firm*", Oxford University Press (2009).

43. Chandler, A.D., Hikino, T. and Chandler, A.D. "Scale and scope: The dynamics of industrial capitalism", Harvard University Press (2009).

44. de Rezende, L.B., Denicol, J., Blackwell, P., et al. "The main project complexity factors and their interdependencies in complex defence projects", *Project Leadership and Society*, p. 100050 (2022).

45. Kermanshachi, S, and Safapour, E. "Identification and quantification of project complexity from perspective of primary stakeholders in US construction projects", *Journal of Civil Engineering and Management*, **25**(4), pp. 380-398 (2019).

46. Kermanshachi, S., Dao, B., Rouhanizadeh, B., et al. "Development of the project complexity assessment and management framework for heavy industrial projects", *International Journal of Construction Education and Research*, **16**(1), pp. 24-42 (2020).

47. Herszon, L. and Keraminiyage, K., "Dimensions of project complexity and their impact on cost estimation", *Project Management Institute* (2014).

48. Aghamohagheghi, M., Hashemi, S.M. and Tavakkoli-Moghaddam, R. "An advanced decision support framework to assess sustainable transport projects using a new uncertainty modeling tool: Interval-valued Pythagorean trapezoidal fuzzy numbers", *Iranian Journal of Fuzzy Systems*, **18**(1), pp. 53-73 (2021).

49. Ghannadpour, S.F., Noori, S. and Tavakkoli-Moghaddam, R. "Multiobjective dynamic vehicle routing problem with fuzzy travel times and customers' satisfaction in supply chain management", *IEEE Transactions on Engineering Management*, **60**(4), pp. 777-790 (2013).

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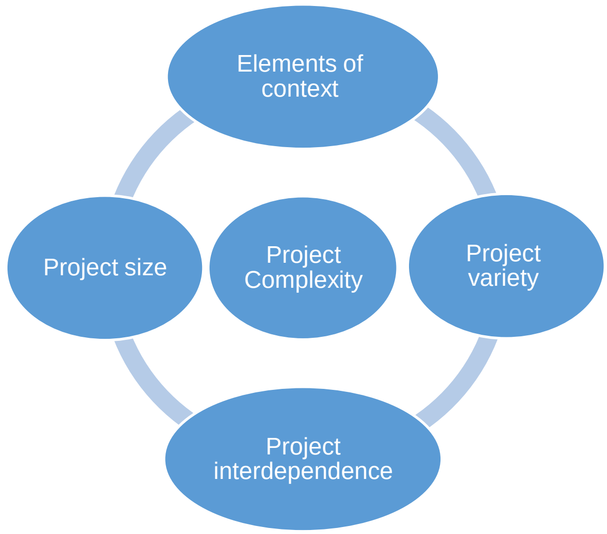
Table 4. Results of the TOPSIS method for calculating the index CC_i



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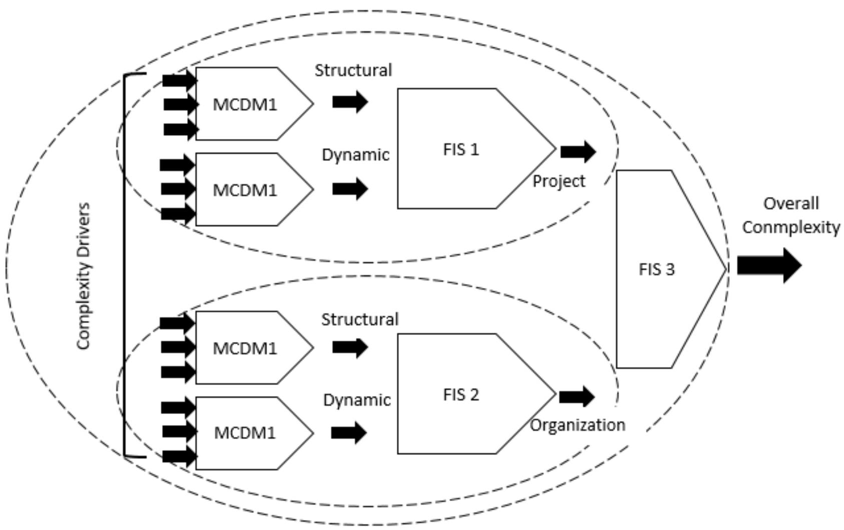

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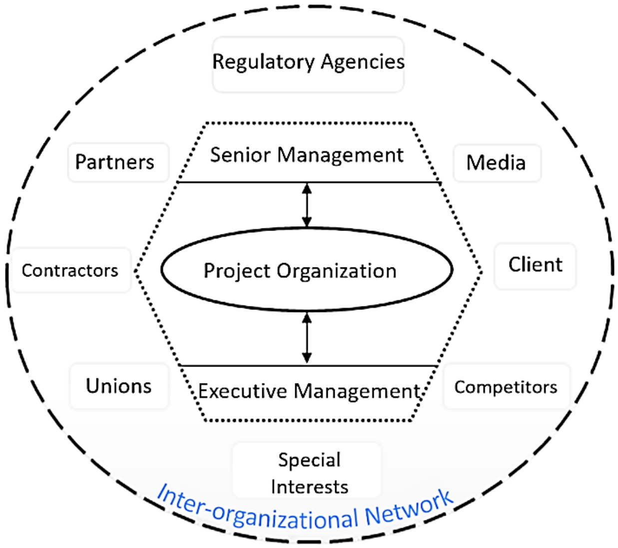

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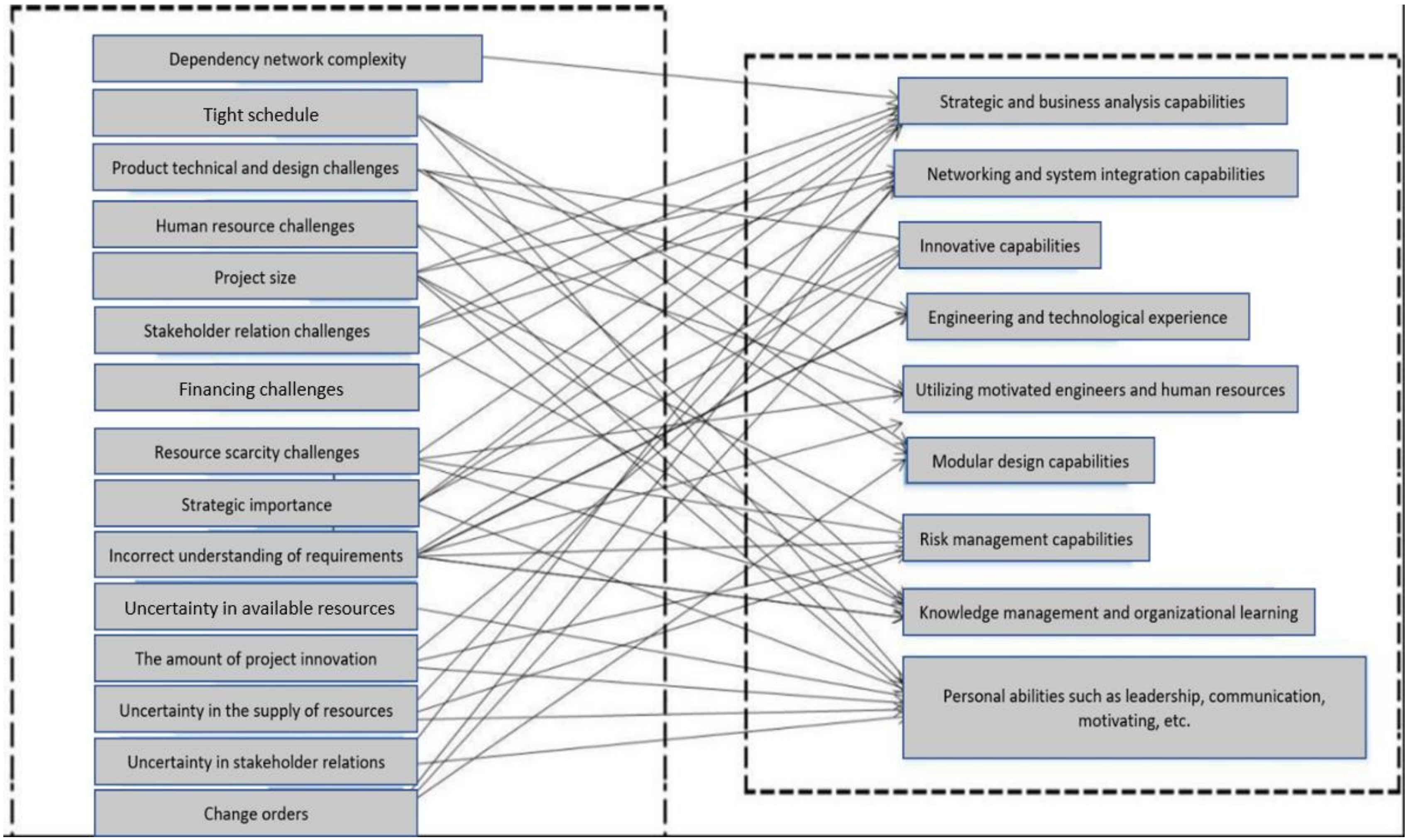

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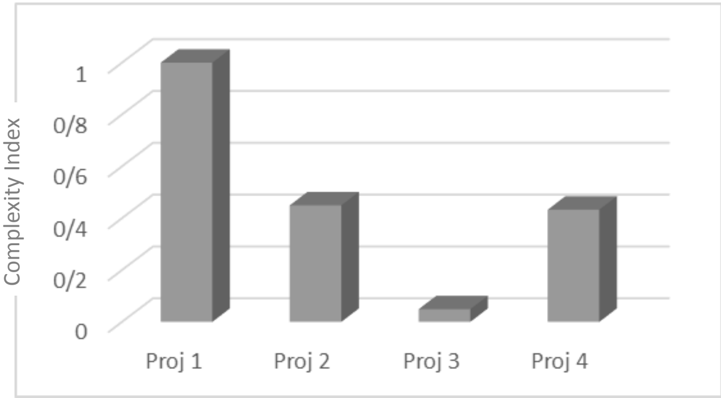

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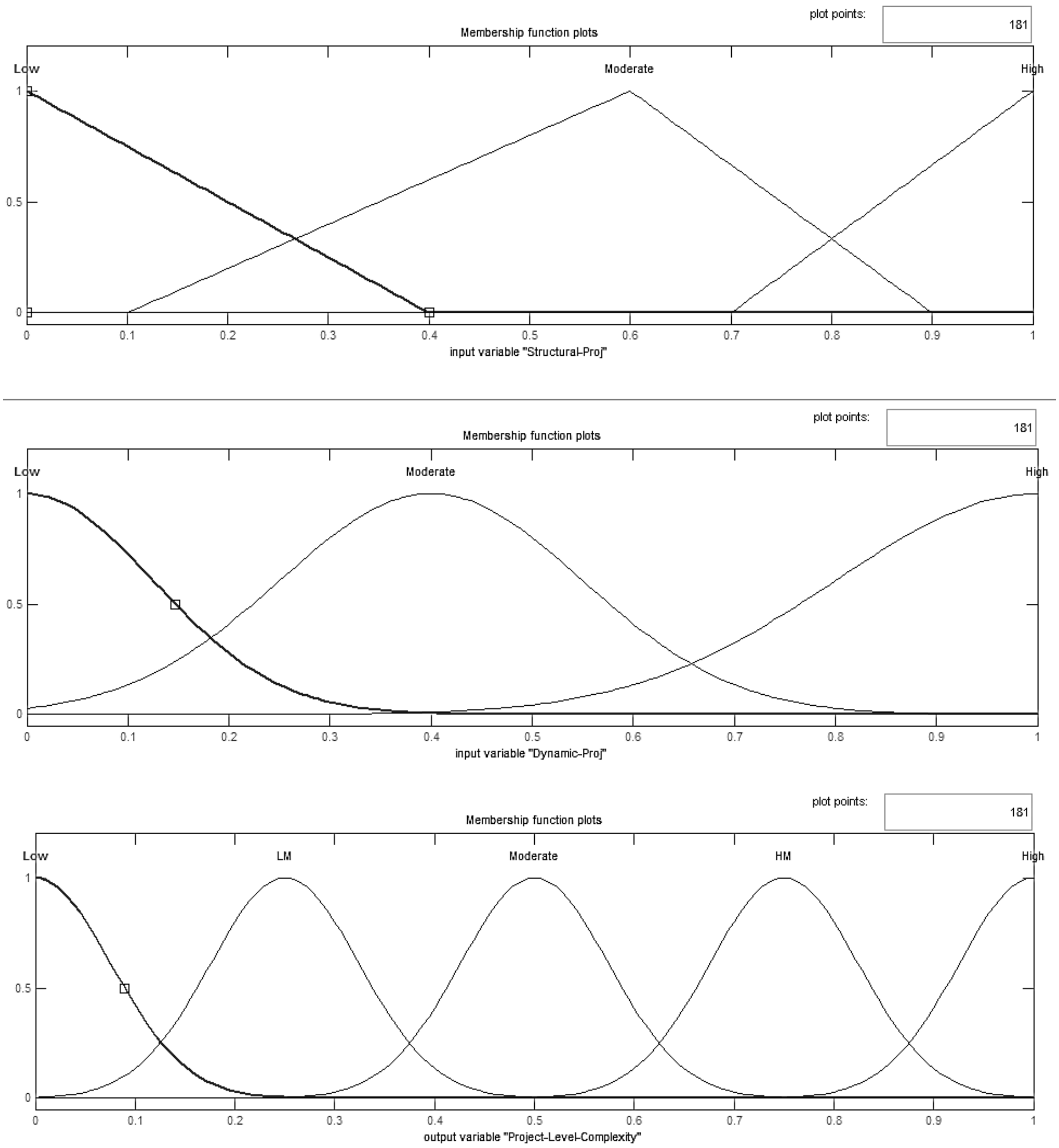
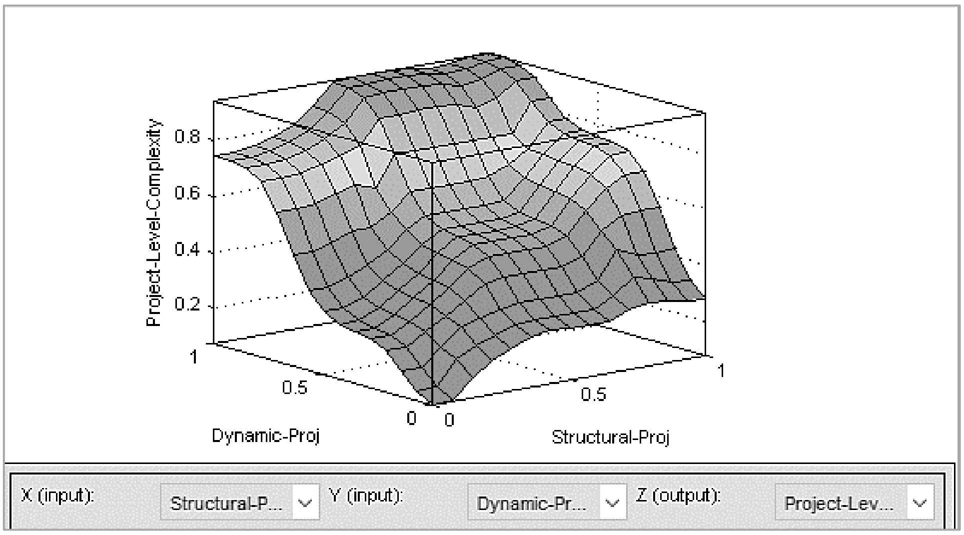


Project Level Complexity			
	S_P	*D_P*	*PLC*
1	*L*	*L*	*L*
2	*L*	*M*	*ML*
3	*L*	*H*	*MH*
4	*M*	*L*	*ML*
5	*M*	*M*	*M*
6	*M*	*H*	*H*
7	*H*	*L*	*ML*
8	*H*	*M*	*MH*
9	*H*	*H*	*H*
	IF		**Then**

Fig. 6. Components of the first phase fuzzy inference system (project-level complexity)



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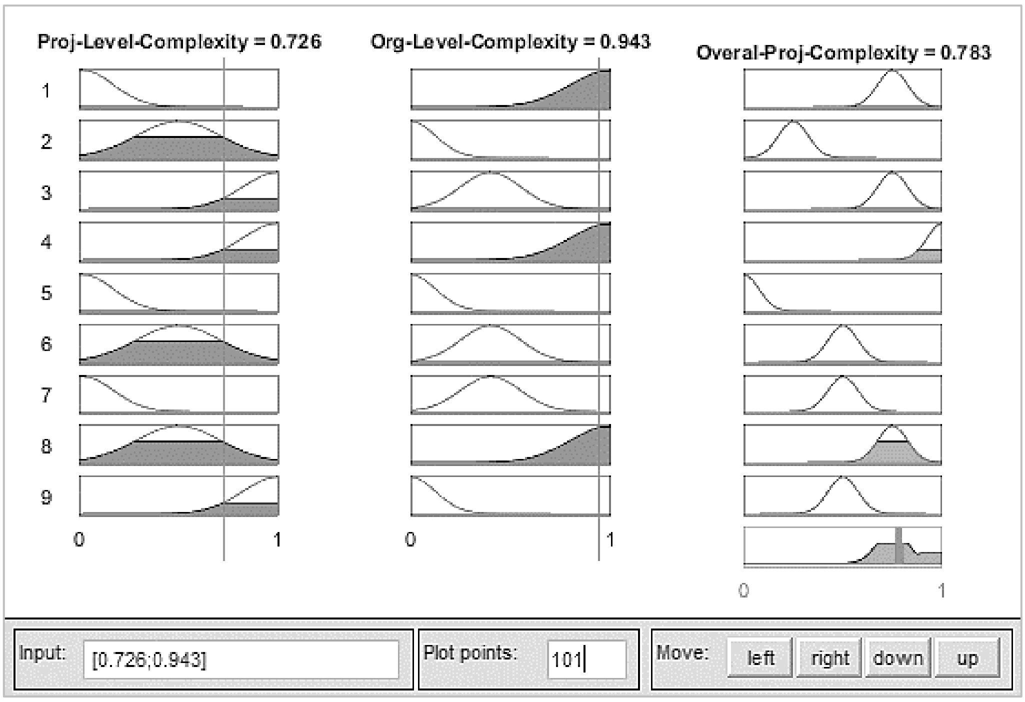

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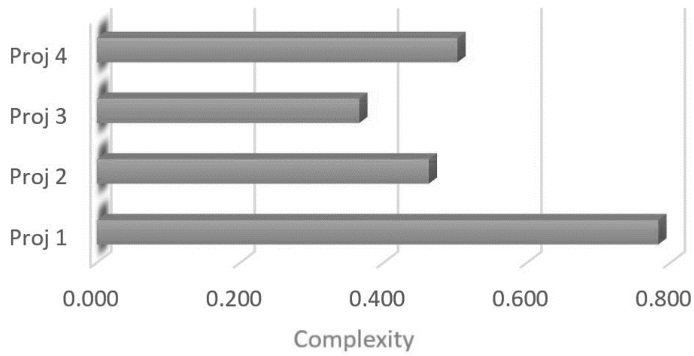

Fig. 9. Overall complexity of projects

Fig. 10. Results of identified key competencies

Table 1. Complexity drivers, according to their nature

	Structural drivers	Dynamic drivers
Organizational level	• Organizational competencies (technical, managerial, financial) • Stakeholder management challenges • Type of contracts and collaboration • The number of funding resources available • The strategic significance of the project	• ambiguity in goals (multiplicity and contradiction in goals) • Trends in stakeholder communications and expectations • Change trends in scope (change order) • Uncertainty in the project resource allocation
Project level	• Project management complexities • Technical and technological complexities • Operational complexities • Complexities of communication between project components	• Uniqueness and innovation of the project • Dependency on other departments and companies • Lack of previous experience with the technology used • Uncertainty in methods (amount of recognition)

Table 2. Normalized decision matrix

Project/ Driver	Project size	HR (team) challenges	Technological challenges	Schedule tightness	Scheduling challenges
Project 1	(0.9,1,1)	(0.56,0.78,1)	(0.85,0.975,1)	(0.9,1,1)	(0.9,1,1)
Project 2	(0.55,0.75,0.9)	(0.33,0.56,0.78)	(0.3,0.5,0.7)	(0.7.0,9,1)	(0.5,0.7,0.9)
Project 3	(0.25,0.45,0.65)	(0.083,0.28,0.5)	(0.45,0.65,0.85)	(0.4,0.6,0.8)	(0.3,0.5,0.7)
Project 4	(0.45,0.65,0.825)	(0.31,0.5,0.72)	(0.45,0.65,0.85)	(0.45,0.65,0.85)	(0.7,0.9,1)

Table 3. Positive and negative ideal fuzzy solutions

A+ (FPIS)	(0.16,0.17,0.17)	(0.1,0.12,0.12)	(0.013,0.15,0.16)	(0.19,0.26,0.34)	(0.19,0.19,0.22)
A- (FNIS)	(0.16,0.17,0.17)	(0.05,0.07,0.09)	(0.05,0.08,0.11)	(0.03,0.09,0.17)	(0.05,0.1,0.14)

Table 4. Results of the TOPSIS method for calculating the index CC_i

Project	d_i^-	d_i^+	CC_i	Rank
1	0.48	0	1	1
2	0.22	0.27	0.45	2
3	0.023	0.46	0.05	4
4	0.21	0.28	0.43	3