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Evaluation of Project Management Methodologies Success Factors Using Fuzzy Cognitive Map Method: Waterfall, Agile, And Lean Six Sigma Cases

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Abstract: A methodology for project management refers to a set of guidelines that defines how to work and communicate while working as a project member. Waterfall practice is the old methodology. As a response to dealing with the difficulty of software development, it has turned out to the most widely utilized methodologies of project management in the software and management industries. Oher software development focused project management method, Agile, has appeared as a response to the shortcoming of Waterfall tool for handling complex projects. Lean Six Sigma is the combination of the main strategies of Six Sigma and Lean. This paper aims to reveal success factors of these three project management methodologies employing Fuzzy cognitive map (FCM) technique, which combines fuzzy logic and neural networks. Presence of cause-and-effect relationships between pair of success indicators and unavailability of crisp data led us to use FCM method in order to determine the most significant criteria of these project management methodologies. This is the first study that considers multiple and conflicting criteria of success factors of waterfall, agile, and lean six sigma project management methodologies. There is no study that aims to provide success criteria evaluation of waterfall, agile, and lean six sigma project management methodologies. This assessment is crucial for companies that have to be managed effectively their project processes in increasing technology and market competition. FCM is a suitable tool to solve this problem since it considers positive and negative relationships, causal links among criteria with their direction, and it is applicable in the absence of crisp data.

Keywords: *Decision making, fuzzy cognitive maps, project management*

1. Introduction

Project management methodology can be delineated as a set of methodologies, tools, frameworks, rules, templates and practices that are utilized in the project. In the early 1990s, companies started to use information technology and software engineering, which encouraged the organizations for employing project management methodologies to survive and then advance in competitive technologic environment. Traditional project management practices that were introduced in the early 1950s provide methods and approaches to track and manage the project. The methods used in the methodology generally do not change from project to project and are uniform. With this traditional approach, assuming that projects are relatively simple, foreseeable, and linear with clearly defined bounds, it's easy to plan everything in detail and keep track of it without major changes.

Traditional project management has not been able to meet today's project requirements over the years. The failure of the projects that make up the bulk of corporate investment or failure to meet requirements led to the search for alternative methods to project management methods. The organizations adopted project management methodologies to sustain organizational success with the aim of effective goal management. The use of project management methodologies provides efficient planning, budgeting and scheduling processes and high management quality for companies [1].

As a result, a lot of different methodologies were developed and used to reach better ways of describing the project requirements, defining the problem, and employing it in a systematic manner. Waterfall project management methodology is linear and sequential; however, it is mostly ineffective in defining the client requirements, managing cost, frequently fluctuant project requirement, and delivery time. In 2001, agile project management methodology came forward in response to cope with waterfall project methodology's limitations that arise from unpredictable customer needs, technologic evolution, and unsteady business environments [1]. Agile project idea is an iterative method in which project processes are planned and managed. An agile project is achieved in iterations, as in agile software development. Lean Six Sigma (LSS) that is the newly developed approach was discovered with the combination of two different concepts, which are named as lean and six sigma [2]. Its goals are boosting shareholder worth by enabling high quality, speed, customer satisfaction and costs. Tools and principles of Lean and Six Sigma have to be integrated with a harmony. Six sigma project management methodology focuses on accuracy and precision, however lean project management methodology concentrates on

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efficiency and speed. Lean provides efficient resource utilization, whereas six sigma enables that work should be done without doing any error [3].

The purpose of this paper is to employ fuzzy cognitive map (FCM) technique in order to reveal the success factors of three project management methodologies named as waterfall, agile and lean six sigma. FCM tool is suitable for the problem due to the lack of crisp data and causal links among success criteria. Initially, 15 success factors of project management are listed through literature review and expert opinions. Afterwards, decision makers determine the causal relations between pair of factors for each project management methodology. Finally, according to the weight of each factor of each project management methodology, the most important criteria are decided for waterfall, agile, and six sigma project management tools, separately. These evaluation criteria will be helpful to the top managers for making managerial decisions during the processes of many projects in the increasing technology.

The contributions of the proposed approach to the project management literature can be listed as follows. First, this is the first study that considers multiple and conflicting criteria of success factors of waterfall, agile, and lean six sigma project management methodologies. Throughout the literature, there is no study that aims to provide success criteria evaluation of waterfall, agile, and lean six sigma project management methodologies. However, this assessment is crucial for companies that have to be managed effectively their project processes in increasing technology and market competition. Second, FCM is a suitable tool to solve this problem since it considers positive as well as negative relationships, causal links among criteria with their direction, and it is applicable in the absence of crisp data. Third, the proposed approach will be a guideline for the managers who are supposed to manage the projects with waterfall, agile, or lean six sigma procedures. From this point, they will be able to increase the performance of conducted projects by focusing on the significant factors that influence the success of the project.

Section 2 of the study reviews the research that evaluate decision-making techniques for evaluating project management tools. Section 3 describes FCM methodology. Proposed decision algorithm is outlined in the subsequent section. Section 5 explains the case study. Results and discussions are outlined in Section 6. Conclusions and future research directions are given in the last section.

2. Literature Review

Throughout the project management literature, researchers have provided contributions to the field by introducing some decision aid techniques. Cockburn [4] indicated main factors of project methodology evaluation problem. Lova and Tormos [5] made an analysis on heuristic multiple project scheduling technique in construction industry and assessed this technique's performance taking into consideration heuristics. Raffo [6] determined project performance indicators and forecasted the performance of a project. Vidal et al. [7] specified the project complexity degree by combining analytic hierarchy process (AHP) and Delphi techniques. They indicated project complexity degree utilizing AHP methodology. Varajão and Cruz-Cunha [8] ranked the project manager alternatives and assessed the manager's capability.

Petkovic et al. [9] identified project management factors and developed an appropriate project management tool in agile environment utilizing adaptive neuro-fuzzy inference system (ANFIS) and regression analysis. Asan et al. [10] used type-2 fuzzy prioritization technique for risk assessment of a project. Joslin and Müller [11] indicated success criteria of a project and evaluated the relationship between methodologies and performance of the project. García-Melón et al. [12] introduced a decision aid framework to rank the projects using Analytic network process (ANP) technique. Tabrizi et al. [13] indicated the best project portfolio in a firm performing in pharmaceutical industry employing fuzzy DEMATEL tool. Ghorabaee et al. [14] identified the most suitable project applying type-2 fuzzy VIKOR method. Serrador and Pinto [15] employed correlation analysis to assess success indicators of agile project management methodology.

In the recent past, Prascevic et al. [16] obtained the rank-order of optimal resources in a construction project utilizing fuzzy analytic hierarchy process (FAHP). Chen et al. [17] identified and assessed the relevance of cloud customer relationship management (CRM) project with regard to risk management and performance. In the similar manner, Chatterjee et al. [18] constructed a categorization and then prioritization of risk factors for the construction projects by combining DANP and VIKOR techniques. Lei et al. [1] determined performance measures of project management and compared the performance of the Scrum and Kanban methodologies using statistics-based analysis. Petrillo et al. [19] introduced agile project management framework to provide a guideline to companies in decision-making processes of optimizing the BPR, and thus they introduced an agile reengineering model. Yaghoobi [20] indicated success criteria of software projects in information technology applying AHP. Song et al. [21] developed a stochastic multiple attribute acceptability analysis approach for project portfolio selection problem, and provided a case study that is conducted in photovoltaic plants located in Eastern China.

More recently, the scholars have concentrated on specially performance and risk indicators of projects by taking into account project management framework. Zheng et al. [22] made an extension of the type and number of the factors employed in project performance evaluation and conducted a case study in a manufacturer. In a similar way, Eshghi et al. [23] developed an interval type-2 fuzzy decision framework to evaluate the performance of megaprojects in a petro-refinery company. Wu et al. [24] focused on lean management for enhancing the performance of highway projects. On the other hand, Chen et al. [25] integrated DEMATEL and ANP techniques to analyze the risk indicators of a project, thus they aimed to improve organizational performance.

Although the researchers have focused on several decision approaches for evaluating project management methodologies, none of them have proposed an extended guideline to project managers in order to analyze the importance degrees of evaluation criteria of certain project management methodologies. Moreover, scholars have not taken into consideration cause-and-effect relationships among the factors, however evaluation criteria of Waterfall, Agile, and Lean Six Sigma methodologies contain causal links among them. This paper proposes an enhanced and detailed guideline to project managers that provides importance levels of evaluation criteria of these three methodologies.

3. Fuzzy Cognitive Maps

Cognitive maps (CMs), was firstly studied by Tolman in 1948 but they were proposed by Axelrod in 1976, were used in decision support systems in the political and social sciences as a modeling tool [26]. CMs provide modeling reasons and mutual relationships between the guided edges and concepts. There are various types of

CMs. These can be listed as signed, weighted and functional graphics.

CMs can be used in many areas such as forecasting, strategic planning, research and development. In traditional CM, bilateral relations expressed as increase and decrease are used. CMs aim to provide engineering planning in the broadest sense. In doing so, it considers causal connections and manages complexity. They also become a very useful tool for providing the most efficient evaluations by comparing models with real situations [27].

FCM models complicated decision aid systems; it is a causal knowledge-based method, which is originated from the integration of fuzzy logic and neural networks [28]. Hereafter, the method is extended and fuzzy numbers or linguistic terms are incorporated for revealing the causal relationships among concepts in FCM.

FCM consists of directional arrows. These arrows represent nodes representing variables and causal relationships between variables [29]. Here C_i refers to nodes $i = 1, 2, 3, \ldots, N$. N represents the total number of variables. Knots are tied with bows of w_{ij} weight that is the parameter of FCM [30]. Here, the variable is not allowed to affect itself, and all w_{ij}values become zero and causal relationships are valued in the range [-1,1], and the following principles are observed in this causality [31].

- $w_{ij} > 0$ indicates positive causality between concepts C_i and C_j. In other words, any increase\decrease in$C_i$results in an increase\- decrease in C_j.
- $w_{ij} < 0$ indicates negative causality between concepts $C_i$and C_j. In other words, any increase\decrease in C_i results in a decrease\increase in C_j.
- $w_{ij} = 0$ indicates no relation between concepts $C_i$and C_j.

The mathematical expression used in the analysis of FCMs is shown through Eq. (1).

$$A_i^{(k+1)} = f\left(A_i^{(k)} + \sum_{j=1, j\neq i}^{n} A_j^{(k)} w_{ij}\right) \quad (1)$$

$A_i^{(k+1)}$indicates the value of the variable at step $(k+1)$. To obtain this value, the value of the variable in step k is added to the matrix that represents causal relationships first. It is then processed with a threshold function. [31]. The aim of this function is to decrease the variable value to a normalized series.

As a result of performing the appropriate number of iterations in the equation (1) above, it will be possible to make advanced observations in the system and by converting the iteration into a simulation, the existing starting vectors can be differentiated, and this process can be repeated many times. In this way, the effects of the dynamical behaviors of different initial states on the system can be observed by differentiating the initial states. When the examined system shows the defined and repetitive behaviors, the existing simulation is terminated and the output is interpreted according to the values obtained as a result of the last iteration and the process is finalized [32].

4. Proposed Decision Approach

In order to make a robust decision, it is important to indicate the causal links of the problem when data are vague and uncertain. In the developed decision framework, there are cause-and-effect relations among factors. Cause-and-effect relationships between criteria, the lack of crisp data, and the requirements for utilizing linguistic terms or fuzzy numbers led us to employ FCM. The stepwise illustration of the developed methodology is as follows [33].

Step 1. Form a decision-makers committee and indicate the evaluation criteria C_i (i=1,2,..,j,..,N).

Step 2. Sign cause-and-effect relation between each pair of factors. The direction of causalities can be null, negative, or positive.

Step 3. Obtain the data for the power of causal links among the factors from experts by using nine linguistic variables according to a scale taken from FCM literature.

Step 4. Provide the fuzzification of the linguistic data.

Step 5. For each relationship, provide the aggregation of fuzzy numbers via MAX aggregation, then defuzzify the aggregated value employing center of gravity method. This step is conducted using MATLAB Fuzzy Toolbox.

Step 6. Activate the iterative process with the initial vector $A^0 = [1,1,\ldots,1]$.

Step 7. Change the values of the initial vector by formulation (1) and utilize Eq (2) as a transformation function, which restricts the values of $A_i^{(k)}$ in the interval [-1,1].

$$f(x) = \tanh(x) \quad (2)$$

Step 8. Repeat Steps 7-8 until the system reaches equilibrium, and provide the computation of the concept values, ie. importance degrees of factors.

5. Case Study

The selection of the appropriate project management methodology is important for obtaining success in the project. This paper focuses on three project management methodologies, which are named waterfall, agile, and lean six sigma to provide a multi-dimensional view of success factors. It wishes to expose performance indicators of project management methodologies, which are lean six sigma, agile and waterfall to be weighed.

Measuring the importance levels of success indicators of project management methodologies relies on a number of conflicting factors. By the experts' opinions and the literature review, fifteen success factors relevant to evaluate project management methodologies are determined as in Table 1.

Table 1. Success factors of project management methodologies [4,6,9,11,15,19,20]

Label	Concept
C_1	Top-level management support
C_2	Organizational culture
C_3	Clear objectives and goals
C_4	Customer participation
C_5	Monitoring and controlling
C_6	Communication between team members
C_7	Project team's ability to react to change
C_8	Project team's general expertise
C_9	Self-organizing and collaborating team
C_{10}	Level of project planning
C_{11}	Clear requirements and specifications
C_{12}	Understanding the tools and techniques
C_{13}	Structured project procedure and progress reporting
C_{14}	Effective project manager skills
C_{15}	Project complexity

A council of 3 decision-makers (DM_1, DM_2, DM_3) that involves a team leader, a project manager, and a project specialist performed the evaluation process. First, the presence of any relationship among each pair of factors is investigated. Then, the direction and the power of the causal relationships are determined.

5.1. Waterfall

The Waterfall method described by Winston W. Royce in 1970s is the most well-known example of project management methods and has been used by many companies for many years. The waterfall method is effective in environments where the requirements are well defined and the variability is low. A traditional project managed by the waterfall method involves distinct phases as study, analysis and definition of the project and its desired goal, basic design of the output, technical and detailed design, construction and implementation, testing, integration, management and maintenance. This subsection aims to obtain concepts' values of Waterfall project management methodology success. Initially, the data consist of the evaluations of three experts using linguistic terms as given in Table 2.

FCMapper software is used to obtain concepts' values for evaluating success factors of project management methodology by running Equation 1. The value A_i of a concept C_i is calculated by considering the influence of the interrelated concepts (C_j) on the concept C_i. Each concept C_i is represented by A_i^t that denotes the activation level of concept C_i at time step t. The vector $A^t = [A_1^t, A_2^t, ..., A_n^t]$ provides the state of the FCM at time step t.

Formulation (1) is employed with the initial vector $A^0 = [1,1,...,1]$. The values of A_i can be negative, thus the threshold function in Formulation (2) is the suitable. The obtained vector by running the iterative formulation is recognized as the initial vector for the next iteration. These vectors are updated till the equilibrium. In other words, the process continues untill formulation (3) is reached (Büyükavcu et al. 2016).

$$\left| A_i^t - A_i^{t+1} \right| \le \varepsilon \tag{3}$$

where $\varepsilon > 0$, and small enough. The concepts' values of Waterfall project management success factors, which are illustrated in Figure 1, are given in Table 5.

Table 2. Linguistic data related to success factors evaluation of waterfall project management methodology

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
C_1	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(pm,pvs,ps)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)
C_2	(pw,pm,pw)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)
C_3	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(pvs,pvs,pvs)	(z,z,z)	(z,z,z)	(z,z,z)	(nvs,nvs,nvs)
C_4	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)
C_5	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(pm,pvs,ps)	(z,z,z)	(z,z,z)
C_6	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(pw,pm,pw)	(z,z,z)	(ps,pvs,ps)	(z,z,z)	(pm,pvs,ps)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)
C_7	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(ps,pm,pw)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)
C_8	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(pw,pm,pw)	(z,z,z)	(pw,pm,pw)	(z,z,z)	(ps,pm,pw)	(z,z,z)	(ps,pm,pw)	(z,z,z)	(z,z,z)	(ps,pm,pw)	(z,z,z)
C_9	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(ps,pm,pw)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)
C_{10}	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(ps,pvs,ps)	(z,z,z)	(ps,pvs,ps)	(z,z,z)	(ns,nm,nw)
C_{11}	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(ns,nvs,ns)
C_{12}	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(ps,pm,pw)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)
C_{13}	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(pm,pvs,ps)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)
C_{14}	(ps,pm,pw)	(z,z,z)	(pw,pm,pw)	(pw,pm,pw)	(pm,ps,ps)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(ps,pvs,ps)	(pw,pm,pw)	(z,z,z)	(pm,pvs,pvs)	(z,z,z)	(z,z,z)
C_{15}	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)	(nm,ns,ns)	(ns,nvs,ns)	(z,z,z)	(z,z,z)	(z,z,z)	(z,z,z)

The linguistic variables are converted into triangular fuzzy numbers as shown in Table 3. After, with MAX method, fuzzy numbers are aggregated. Finally, these aggregated fuzzy numbers are defuzzified employing center of gravity method.

Table 3. Scale of triangular fuzzy numbers [34]

Linguistic Term	Fuzzy Number
nvs	(-1,-1,-0.75)
ns	(-1,-0.75,-0.5)
nm	(-0.75,-0.5,-0.25)
nw	(-0.5,-0.25,0)
z	(-0.25,0,0.25)
pw	(0,0.25,0.5)
pm	(0.25,0.5,0.75)
ps	(0.5,0.75,1)
pvs	(0.75,1,1)

The final crisp values for each cause-and-effect relationship are determined and the weight matrix is obtained as shown in Table 4.

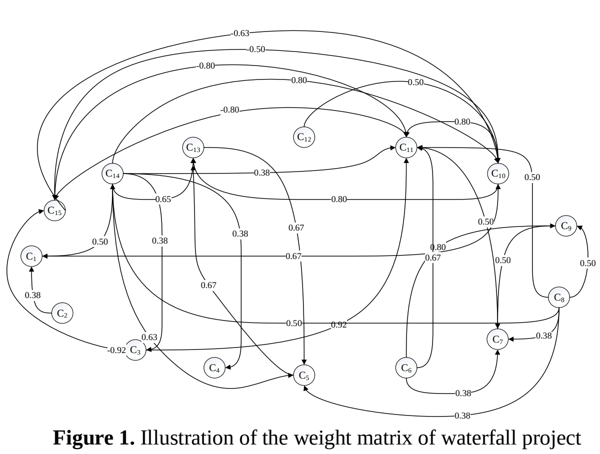

Figure 1. Illustration of the weight matrix of waterfall project management methodology

Table 4. Weight matrix of waterfall project management methodology

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
C_1	0	0	0	0	0	0	0	0	0	0.67	0	0	0	0	0
C_2	0.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_3	0	0	0	0	0	0	0	0	0	0	0.92	0	0	0	-0.92
C_4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_5	0	0	0	0	0	0	0	0	0	0	0	0	0.67	0	0
C_6	0	0	0	0	0	0	0.38	0	0.80	0	0.67	0	0	0	0
C_7	0	0	0	0	0	0	0	0	0	0	0.50	0	0	0	0
C_8	0	0	0	0	0.38	0	0.38	0	0.50	0	0.50	0	0	0.50	0
C_9	0	0	0	0	0	0	0.50	0	0	0	0	0	0	0	0
C_{10}	0	0	0	0	0	0	0	0	0	0	0.80	0	0.80	0	-0.50
C_{11}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.80
C_{12}	0	0	0	0	0	0	0	0	0	0.50	0	0	0	0	0
C_{13}	0	0	0	0	0.67	0	0	0	0	0	0	0	0	0	0
C_{14}	0.50	0	0.38	0.38	0.63	0	0	0	0	0.80	0.38	0	0.65	0	0
C_{15}	0	0	0	0	0	0	0	0	0	-0.63	-0.80	0	0	0	0

Table 5. The weights of waterfall project management methodology success criteria

Success criteria	Weights
C_1	0.73484
C_2	0.03868
C_3	0.67271
C_4	0.67271
C_5	0.95347
C_6	0.03868
C_7	0.78979
C_8	0.03868
C_9	0.50321
C_{10}	0.98442
C_{11}	0.99897
C_{12}	0.03868
C_{13}	0.99028
C_{14}	0.37610
C_{15}	-0.99404

5.2. Agile

The term Agile is raised as a project management ideology in 2001. Organizations, which use agile methodology face some challenges about management practice. As Agile involves collaboration and self-organization, traditional organizations in which employees used to work alone according to commend of their managers can also face with resistance to change. While traditional projects focus on precise descriptions of the project's output/ products at the beginning, Agile starts with understanding of expectations, which can be changed and evolve. That's why, understanding the needs with its all aspects and making logical estimations is the key point. In traditional way, customer comes to an agreement with project development team for end product before starting the project. On the contrary in Agile, customers and developers have continuous and close collaboration during the process. This subsection reaches concepts' values of agile project management methodology success. The evaluation data of three decision-makers using linguistic terms are given in Table 6.

The weight matrix that is formed for success factors evaluation of Agile project management methodology is provided in Table 7. After running the iterative formulation of FCM, concepts' values of Agile project management success factors are outlined in Table 8 and they are illustrated in Figure 2.

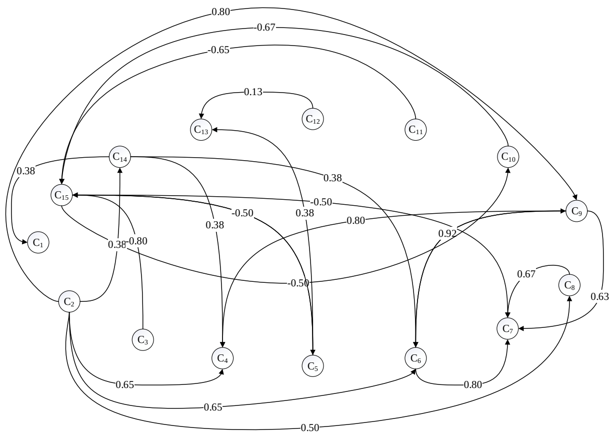

Figure 2. Illustration of the weight matrix of waterfall project management methodology

Table 6. Linguistic data related to success factors evaluation of agile project management methodology

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
C_1	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
C_2	(0,0,0)	(0,0,0)	(0,0,0)	(pm,pvs,pvs)	(0,0,0)	(pm,pvs,pvs)	(0,0,0)	(ps,pm,pw)	(ps,pvs,ps)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pw,pm,pw)	(0,0,0)
C_3	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(ns,nvs,ns)
C_4	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
C_5	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pw,pm,pw)	(0,0,0)	(ns,nm,nw)
C_6	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(ps,pvs,ps)	(0,0,0)	(pvs,pvs,pvs)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
C_7	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
C_8	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pm,pvs,ps)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
C_9	(0,0,0)	(0,0,0)	(0,0,0)	(ps,pvs,ps)	(0,0,0)	(ps,pvs,ps)	(pm,ps,ps)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
C_{10}	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(nm,nvs,ns)
C_{11}	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(nm,nvs,nvs)
C_{12}	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pw,pw,z)	(0,0,0)	(0,0,0)
C_{13}	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
C_{14}	(pw,pm,pw)	(0,0,0)	(0,0,0)	(pw,pm,pw)	(0,0,0)	(pw,pm,pw)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
C_{15}	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(nm,ns,ns)	(0,0,0)	(nm,ns,nw)	(0,0,0)	(0,0,0)	(ns,nm,nw)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)

Table 7. Weight matrix of agile project management methodology

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
C_1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_2	0	0	0	0.65	0	0.65	0	0.50	0.80	0	0	0	0	0.38	0
C_3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.80
C_4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_5	0	0	0	0	0	0	0	0	0	0	0	0	0.38	0	-0.50
C_6	0	0	0	0	0	0	0.80	0	0.92	0	0	0	0	0	0
C_7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_8	0	0	0	0	0	0	0.67	0	0	0	0	0	0	0	0
C_9	0	0	0	0.80	0	0.80	0.63	0	0	0	0	0	0	0	0
C_{10}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.67
C_{11}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.65
C_{12}	0	0	0	0	0	0	0	0	0	0	0	0	0.13	0	0
C_{13}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_{14}	0.38	0	0	0.38	0	0.38	0	0	0	0	0	0	0	0	0
C_{15}	0	0	0	0	-0.63	0	-0.50	0	0	-0.50	0	0	0	0	0

Table 8. The weights of agile project management methodology success criteria

Success criteria	Weights
C_1	0.68650
C_2	0.06525
C_3	0.06525
C_4	0.95788
C_5	0.90877
C_6	0.95788
C_7	0.99631
C_8	0.44262
C_9	0.95554
C_{10}	0.87695
C_{11}	0.06525
C_{12}	0.06525
C_{13}	0.82804
C_{14}	0.40700
C_{15}	-0.97089

5.3. Lean Six Sigma

Lean Six Sigma method emerges from the integration of the basic concepts of Six Sigma and Lean. The reduction and elimination of process wastes are provided with the help of lean principles while six sigma focuses on variation and reduction in each process. Hence, lean six-sigma aims to improve the productivity and quality of the process. This subsection aims to obtain concepts' values of Lean Six Sigma project management methodology success. Linguistic data collecting from the experts are given in Table 9. The weight matrix of success factors evaluation of Lean Six Sigma project management methodology is provided in Table 10.

Concepts' values of Lean Six Sigma project management success are obtained via iterative formulation of FCM as in Table 11 and they are illustrated in Figure 3.

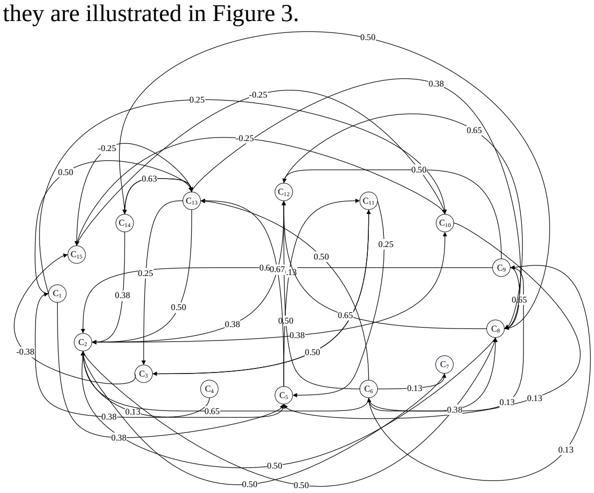

Figure 3. Illustration of the weight matrix of lean six sigma project management methodology

Table 9. Linguistic data related to success factors evaluation of lean six sigma project management methodology

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
C_1	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pw,pm, pw)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pw,pm, z)	(0,0,0)	(0,0,0)	(ps,pm, pw)	(0,0,0)	(0,0,0)
C_2	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(ps,pm, pw)	(0,0,0)	(pw,pm, pw)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
C_3	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(ps,pm, pw)	(0,0,0)	(0,0,0)	(0,0,0)	(nw,nm, nw)
C_4	(0,0,0)	(pw,pw, z)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
C_5	(pw,pm, pw)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pw,pw, z)	(0,0,0)	(pm,pvs, ps)	(0,0,0)	(0,0,0)
C_6	(0,0,0)	(pm,pvs, pvs)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pw,pw, z)	(pw,pm, pw)	(pw,pw, z)	(0,0,0)	(0,0,0)	(ps,pm, pw)	(ps,pm, pw)	(0,0,0)	(0,0,0)
C_7	(0,0,0)	(ps,pm, pw)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
C_8	(0,0,0)	(ps,pm, pw)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pm,pvs, pvs)	(0,0,0)	(ps,pm, pw)	(0,0,0)
C_9	(0,0,0)	(pm,pvs, pvs)	(0,0,0)	(0,0,0)	(0,0,0)	(pw,pw, z)	(0,0,0)	(pm,pvs, pvs)	(0,0,0)	(0,0,0)	(0,0,0)	(ps,pm, pw)	(0,0,0)	(0,0,0)	(0,0,0)
C_{10}	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pw,pw, z)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(nw,nm, z)
C_{11}	(0,0,0)	(0,0,0)	(ps,pm, pw)	(0,0,0)	(pw,pm, z)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
C_{12}	(0,0,0)	(pw,pm, pw)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pm,pvs, pvs)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
C_{13}	(0,0,0)	(ps,pm, pw)	(pw,pm, z)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pw,pm, pw)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pm,ps, ps)	(nw,nm, z)
C_{14}	(0,0,0)	(pw,pm, pw)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(pm,pvs, pvs)	(0,0,0)	(0,0,0)
C_{15}	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(nw,nm, z)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)

Table 10. Weight matrix of lean six sigma project management methodology

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
C_1	0	0	0	0	0.38	0	0	0	0	0.25	0	0	0.50	0	0
C_2	0	0	0	0	0	0	0	0.50	0	0.38	0	0	0	0	0
C_3	0	0	0	0	0	0	0	0	0	0	0.50	0	0	0	-0.38
C_4	0	0.13	0	0	0	0	0	0	0	0	0	0	0	0	0
C_5	0.38	0	0	0	0	0	0	0	0	0	0.13	0	0.67	0	0
C_6	0	0.65	0	0	0	0	0.13	0.38	0.13	0	0	0.50	0.50	0	0
C_7	0	0.50	0	0	0	0	0	0	0	0	0	0	0	0	0
C_8	0	0.50	0	0	0	0	0	0	0	0	0	0.65	0	0.50	0
C_9	0	0.65	0	0	0	0.13	0	0.65	0	0	0	0.50	0	0	0
C_{10}	0	0	0	0	0.13	0	0	0	0	0	0	0	0	0	-0.25
C_{11}	0	0	0.50	0	0.25	0	0	0	0	0	0	0	0	0	0
C_{12}	0	0.38	0	0	0	0	0	0.65	0	0	0	0	0	0	0
C_{13}	0	0.50	0.25	0	0	0	0	0.38	0	0	0	0	0	0.63	-0.25
C_{14}	0	0.38	0	0	0	0	0	0	0	0	0	0	0.65	0	0
C_{15}	0	0	0	0	0	0	0	0	0	-0.25	0	0	0	0	0

Table 11. The weights of lean six sigma project management methodology success criteria

Success criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Weight	0.82586	0.99896	0.92536	0.26164	0.91871	0.56104	0.56104	0.99583	0.56104	0.94310	0.90229	0.97495	0.99436	0.97013	-0.94478

6. Results and Discussions

Success of a project depends on various factors that are to be taken into account for maintaining sustainable performance. A project manager as well as project team members should recognize these factors and work for achieve them in order to obtain a successful project at the end. In this technologic world, these success indicators are generally related to the technologic improvements. In global competitive markets, organizations should keep up with the new trends and changing technologies while conducting their projects. Thus, identifying the factors that are effective on the success of a project as well as determining the most appropriate project management methodology for a specific project are the key points to obtain successful project. Hence, organizations should closely know the differences and similarities between project management methodologies and the important factors on the success of a project that is conducted using one of these methodologies.

Waterfall project management is based on planning, and the processes are completed phase by phase. This consecutive procedure, in other words a phase can start only the other phase is finished, increases the significance of the planning. Initially, the requirements are determined and then described and analyzed.

Afterwards, development phases begin after analyzing process. In final phase, the outputs are tested by the users. According to the importance degrees of the success factors of Waterfall project management methodology, clear requirements and specifications, and structured project procedure and progress reporting are the most important criteria. And also, level of project planning is an effective on a project that is managed with Waterfall strategy. Contrarily, project complexity has a negatively significant effect.

On the other hand, the importance of organizational culture is low, since only the companies that aim to improve themselves focus on the cultural progress. Organizational culture represents the processes without failure. Waterfall strategy is an ancient procedure, hence the companies that have high cultural structure do not prefer Waterfall strategy whereas the firms that could not improve themselves regarding culture may easily apply Waterfall project management tool. Moreover, communication between team members and project team's general expertise are also the least important Waterfall success criteria, they are rather agile related factors. Likewise, as Waterfall has a traditional structure, understanding the tools and techniques has almost no effect on the project's success. Thus, organizational culture, communication between team members, project team's general expertise, and understanding the tools and techniques can be eliminated from success factors of Waterfall project management methodology.

Agile project management is based on keeping up with the changes, and collaboration between project team members. With regard to the results of the success factors of Agile strategy, the most important criteria are project team's ability to react to change, and self-organizing and collaborating team. Besides, project complexity has a negative effect on project's success as in Waterfall strategy. On the other hand, the importance degree of organizational culture is low because of the basic "no failure" principle of organizational culture. Furthermore, there is no need for determining the project's objectives in each phase in Agile strategy unlike Waterfall. Thus, clear objective and goals has a low importance level. In addition, requirements and specifications are not needed to be indicated for the whole project at the beginning of the project process. They are determined for each phase in the related phase, and thus clear requirements and specifications have no significant importance for an agile-managed project. As agile strategy is not technique-based project management methodology, is a communication-based strategy. Hence, understanding the tools and techniques have very low weight. Finally, organizational culture, Clear objectives and goals, Clear requirements and specifications, and understanding the tools and techniques can be omitted from success factors of Agile project management methodology.

Lean Six Sigma project management methodology is based on "no failure" strategy, hence the influence degree of organizational culture on the success of a project that will be managed with Lean Six Sigma is very high. Moreover, the project team should be skilled and experienced on the project methodology process and procedure, and thus project team's general expertise and effective project manager skills are one of the most important success factors of Lean Six Sigma strategy. Since Lean Six Sigma is technique-based project management methodology, understanding the tools and techniques has very high effect. On the other hand, customer participation is the least important success factor, because the customer is not included in the whole project in Lean Six Sigma strategy unlike Agile. Customers are included in the process only after analyzing step. For that reason, customer participation factor can be eliminated from success factor assessment of Lean Six Sigma strategy.

7. Conclusions

This paper aims to weight success factors of project management methodologies that are most widely used nowadays, named as Waterfall, Agile and Lean Six Sigma. First, fifteen success indicators of project management methodologies are determined through expert opinions and literature survey. Then, causal relations between pair of factors for each project management methodology are assigned by three decision makers. Lastly, importance degrees assigned to each factor of each project management methodology are calculated by employing FCM technique. The most important criteria for waterfall, agile and six sigma project management tools are determined by the result of FCM, likewise the least important criteria are indicated as they can be eliminated from the evaluation. These assessment criteria will be useful and helpful for top managers to make managerial decisions during the processes of many projects in the increasing technology and competitive environment.

The contributions of this paper to the literature can be summarized as follows. First, this is the first paper that evaluates success factors of waterfall, agile, and lean six sigma project management methodologies. Second, FCM is an appropriate technique to solve this problem since it considers both positive and negative relationships, causal links among criteria with their direction, and it is applicable when the data contain fuzziness and vagueness, and thus when crisp data are not available. Third, the developed decision approach will be a guideline for the managers who manage the projects with waterfall, agile, or lean six sigma procedures. By making use of the results of the proposed approach, they will have an opportunity for improving the outputs of the project and increase the whole project performance. Hence, this study represents a guideline for the project managers or team leaders who aim to reach success in their projects.

Future research will probably focus on employing a rule-based FCM technique in order to observe and interpret weights of evaluation criteria by incorporating the results obtained via adding the rules.

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