Project Management Methodologies Success Factors Evaluation Employing Intuitionistic Fuzzy Cognitive Map Method

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Abstract

Project management methodologies describe the way of working and communicating, and represent the principles and processes in order to manage a 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 presents an intuitionistic fuzzy cognitive map (IFCM) application to evaluate the importance degrees of performance indicators of these project management methodologies. The cause-and-effect relationships among concepts; uncertainty, vagueness, and hesitation in data lead to utilize an intuitionistic decision aid approach to assess the performance criteria of project management frameworks.

Keywords
Project management, intuitionistic fuzzy cognitive maps, uncertainty, hesitation

1. Introduction
Organizations started to use project management methodologies only since mid-1900s; however, concept of project management methodology has been used for a very long time in practice (Lei et al. 2017). Throughout the mid-1900s, the first usage area of project management methodologies are defense, navy, and space industries. Project management methodology started to take form with the nascence of critical path method (CPM). These organizations adopted project management methodologies to drive organizational success with effective goal management. In the 1960s,

waterfall model was the most common project management technique thus humankind land on the moon and return to world safely by help of this technique.

A lot of different methodologies were developed and used to reach better ways of defining the project requirements, analyzing the problem, and implementing it in a systematic manner. Some of these methodologies were linear and sequential. Its name is "Waterfall Project Management Methodology". These methods were mostly ineffective in defining the needs of customers, managing frequently changing project requirement, cost and delivery time.

In 2001, agile project management methodologies came forward in response to deal with waterfall project methodology's failures that arise from unpredictability of customer requirements, technology evolution, and unstable business environments (Lei et al. 2017). It was announced to eliminate the problems of waterfall project management methodologies. Agile project idea is an iterative method. Project processes are planned and managed. As in agile software development, an agile project is accomplished in small pieces that are named iterations. The project team, which should involve representatives of the stakeholders of the project, reviews and criticizes each section or iteration. The results obtained from an iteration are used to decide the following project phase (Totten, 2017).

Lean Six Sigma (LSS) that is the newly developed approach was discovered with the combination of two different project management methodologies (Snee, 2010). Its goals are boosting shareholder worth by enabling high quality, speed, customer satisfaction and costs. Tools and principles of Lean and Six Sigma has to be unite with a harmony. Hence, business improvement was ensured. Six sigma project management methodology puts emphasis on accuracy and precision however lean project management methodology places importance on efficiency and speed: lean makes sure that resource utilization is done properly, while six sigma makes sure that work is done without doing any error (Gijo and Antony, 2013).

Throughout the project management literature, researchers have provided contributions to the field by introducing some decision aid techniques. Cockburn (2000) indicated main factors of project methodology evaluation problem. Vidal et al. (2001) specified the project complexity degree by combining analytic hierarchy process (AHP) and Delphi techniques. They indicated project complexity degree utilizing AHP methodology. Asan et al. (2016) used type-2 fuzzy prioritization technique for risk assessment of a project. Joslin and Müller (2016) indicated success criteria of a project and evaluated the relationship between methodologies and performance of the project. Chen et al. (2018) 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. (2018) constructed a categorization and then prioritization of risk factors for the construction projects by combining DANP and VIKOR techniques. Eshghi et al. (2019) developed an interval type-2 fuzzy decision framework to evaluate the performance of megaprojects in a petro-refinery company. Wu et al. (2019) focused on lean management for enhancing the performance of highway projects. The objective of this study is to employ intuitionistic fuzzy cognitive map (IFCM) technique in order to reveal the success factors of three project management methodologies named as waterfall, agile and lean six sigma.
The rest of the study is organized as follows. Section 2 explains IFCM methodology, Section 3 illustrates the case study, and finally conclusions are provided in the last section.

2. Intuitionistic Fuzzy Cognitive Maps

Intuitionistic fuzzy cognitive map (IFCM) technique incorporates intuitionistic fuzzy numbers into cognitive maps for expressing the power of cause-and-effect relationships (Dogu and Albayrak, 2018). Initially, concept nodes and power of causal links among them are defined by obtaining experts' opinions. Afterwards, the power of causal links is represented by intuitionistic fuzzy numbers that are associated with intuitionistic fuzzy scale. Thus, membership, non-membership, and hesitation values are determined. By utilizing the information collected from decision makers, N x N weight matrix is formed.

To calculate the concepts' values, the following iterative formulation is run until the system will be stabilized, in other words, all factor weights will converge (Iakovidis and Papageorgiou, 2011).

$$A_i^{(k+1)} = f\left(A_i^{(k)} + \sum_{\substack{j=1 \\ j\neq i}}^{N} A_j^{(k)} w_{ji}^{\mu} - A_j^{(k)} w_{ji}^{\pi}) \right) \quad (1)$$

where $A_i^{(k)}$ is the value of concept C_i at k^{th} iteration, w_{ji} is the weight of the connection from C_j to C_i, w_{ji}^{μ} and w_{ji}^{π} denote the weight matrices that show membership values and hesitation values of causal links, respectively, and f is a threshold function, which is considered as sigmoid function for this work.

The application steps of the employed technique are given as follows:

Step 1: Make a consensus formed by project management experts.
Step 2: Determine evaluation criteria (concepts in cognitive map terminology) $i = 1,2,..,j,..,n$.
Step 3: Obtain cause-and-effect relationships between pair of concepts by collecting experts' opinions.
Step 4: Determine membership values for cause-and-effect relationships between pair of concepts.
Step 5: Determine non-membership values for cause-and-effect relationships between pair of concepts.
Step 6: Determine hesitation values for cause-and-effect relationships between pair of concepts.
Step 7: Compute concepts' values by running the iterative formulation (1) of IFCM until the system will be stabilized, in other words the values assigned to the concepts will no longer change.

3. Case Study

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

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

The intuitionistic fuzzy scale is taken from literature as in Table 2.

Table 2. Scale of intuitionistic fuzzy numbers

Linguistic term	Intuitionistic fuzzy number
VH	<0.95,0.05>
H	<0.70,0.25>
M	<0.50,0.40>
L	<0.25,0.70>
VL	<0.05,0.95>

Hesitative data related to Waterfall, Agile, and Lean Six Sigma project management methodologies are given in Tables 3-5, respectively.

Table 3. Hesitative 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	0	0	0	0	0	0	0	0	0	M	0	0	0	0	0
C_2	L	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	VH	0	0	0	VH
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	H	0	0
C_6	0	0	0	0	0	0	L	0	VH	0	M	0	0	0	0
C_7	0	0	0	0	0	0	0	0	0	0	M	0	0	0	0
C_8	0	0	0	0	VL	0	L	0	M	0	M	0	0	M	0
C_9	0	0	0	0	0	0	L	0	0	0	0	0	0	0	0
C_{10}	0	0	0	0	0	0	0	0	0	0	H	0	VH	0	M
C_{11}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	VH
C_{12}	0	0	0	0	0	0	0	0	0	L	0	0	0	0	0
C_{13}	0	0	0	0	H	0	0	0	0	0	0	0	0	0	0
C_{14}	M	0	L	L	M	0	0	0	0	VH	VL	0	M	0	0
C_{15}	0	0	0	0	0	0	0	0	0	H	VH	0	0	0	0

Table 4. Hesitative 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
C_2	0	0	0	M	0	M	0	M	VH	0	0	0	0	L	0
C_3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	H
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	VL	0	M
C_6	0	0	0	0	0	0	H	0	VH	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	L	0	0	0	0	0	0	0	0
C_9	0	0	0	VH	0	VH	H	0	0	0	0	0	0	0	0
C_{10}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	H
C_{11}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M
C_{12}	0	0	0	0	0	0	0	0	0	0	0	0	VL	0	0
C_{13}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_{14}	L	0	0	VL	0	L	0	0	0	0	0	0	0	0	0
C_{15}	0	0	0	0	M	0	M	0	0	H	0	0	0	0	0

Table 5. Hesitative 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	M	0	0	0	0	L	0	0	H	0	0
C_2	0	0	0	0	0	0	0	M	0	L	0	0	0	0	0
C_3	0	0	0	0	0	0	0	0	0	0	M	0	0	0	L
C_4	0	VL	0	0	0	0	0	0	0	0	0	0	0	0	0

C_5	L	0	0	0	0	0	0	0	0	0	VL	0	VH	0	0
C_6	0	M	0	0	0	0	VL	L	VL	0	0	H	H	0	0
C_7	0	M	0	0	0	0	0	0	0	0	0	0	0	0	0
C_8	0	M	0	0	0	0	0	0	0	0	0	H	0	H	0
C_9	0	M	0	0	0	VL	0	H	0	0	0	H	0	0	0
C_{10}	0	0	0	0	VL	0	0	0	0	0	0	0	0	0	L
C_{11}	0	0	M	0	VL	0	0	0	0	0	0	0	0	0	0
C_{12}	0	L	0	0	0	0	0	VH	0	0	0	0	0	0	0
C_{13}	0	M	VL	0	0	0	0	M	0	0	0	0	0	H	VL
C_{14}	0	M	0	0	0	0	0	0	0	0	0	0	H	0	0
C_{15}	0	0	0	0	0	0	0	0	0	L	0	0	0	0	0

Weight matrices of Waterfall, Agile, and Lean Six Sigma project management methodologies are illustrated in Figures 1-3, respectively.

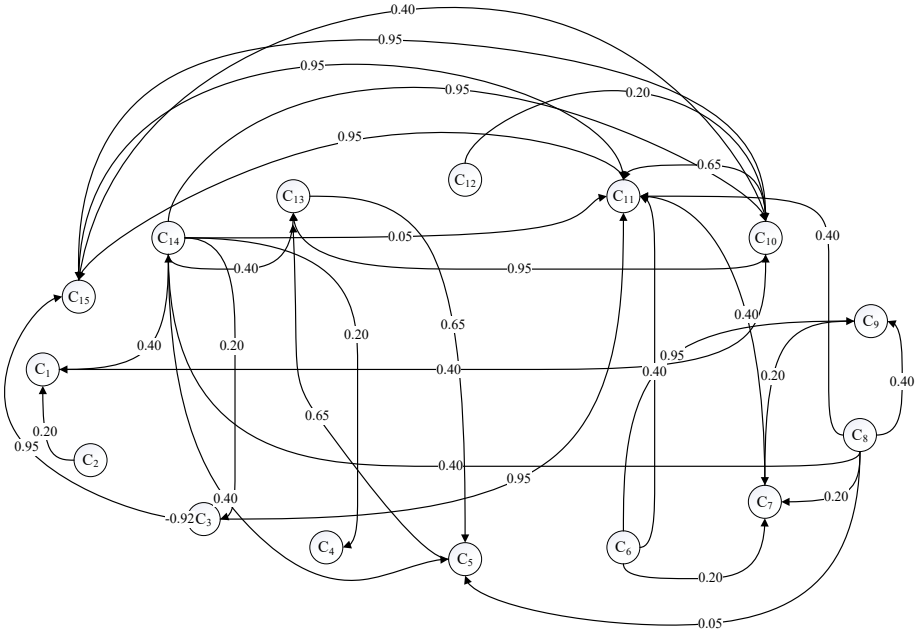

Figure 1. Weight matrix of Waterfall project management methodology

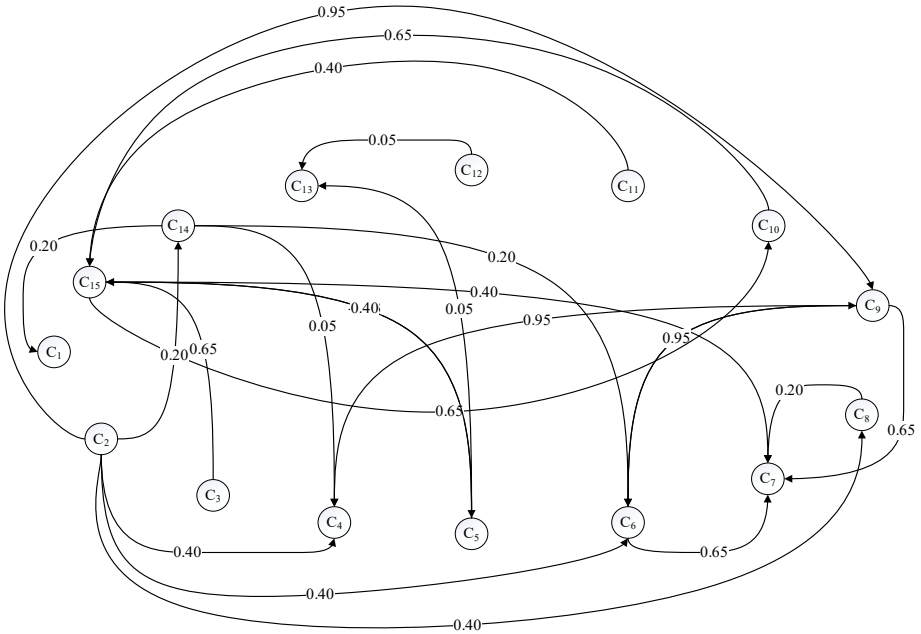

Figure 2. Weight matrix of Agile project management methodology

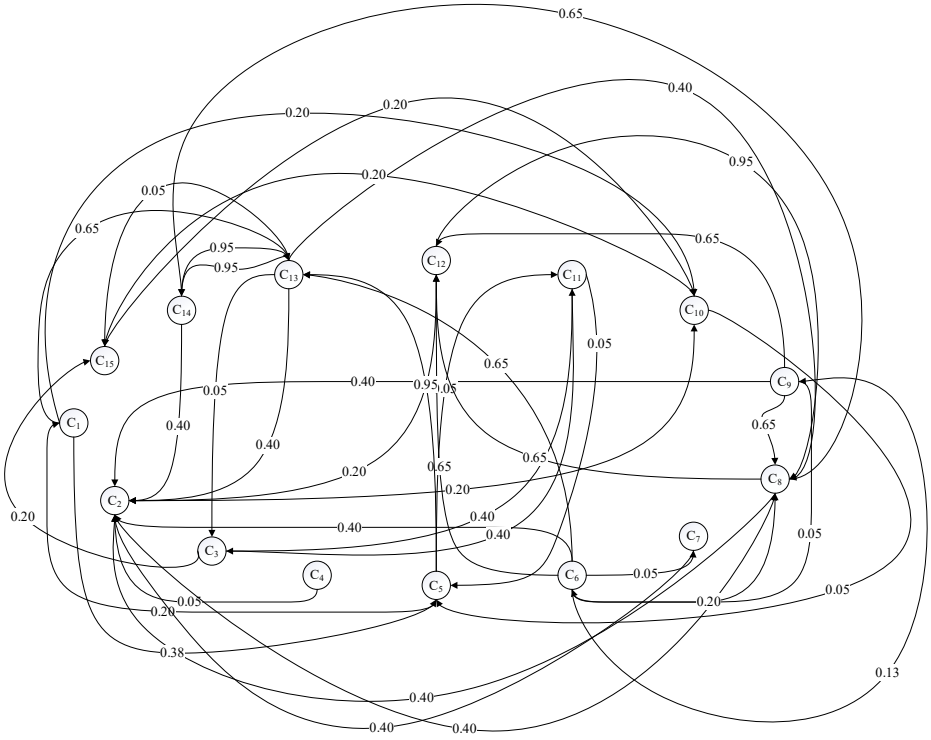

Figure 3. Weight matrix of Lean Six Sigma project management methodology

IFCM technique is applied and the weights performance indicators of project management methodologies are obtained by running the formulation (1) until it will be stabilized, and the values of concepts will no longer change. FCMapper software is used for these operations. The concepts' values given in Table 6.

Table 6. The IFCM weights of project management methodologies success criteria

Success criteria	Waterfall weights	Agile weights	Lean six sigma weights
C_1	0.766839	0.697834	0.700815
C_2	0.659046	0.659046	0.956935
C_3	0.699642	0.659046	0.749604
C_4	0.699642	0.886509	0.659046
C_5	0.856903	0.754389	0.751851
C_6	0.659046	0.897620	0.668649
C_7	0.769020	0.932476	0.668649
C_8	0.659046	0.729753	0.959530
C_9	0.850745	0.916468	0.668649
C_{10}	0.936118	0.802148	0.779195
C_{11}	0.982509	0.659046	0.747410
C_{12}	0.659046	0.659046	0.917630
C_{13}	0.935454	0.679137	0.958703
C_{14}	0.729753	0.695862	0.894895
C_{15}	0.948893	0.919426	0.751171

According to the importance degrees of the success factors of Waterfall project management methodology, clear requirements and specifications, structured project procedure and progress reporting, and project complexity are the most important criteria. 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. 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, the importance degree of organizational culture is low because of the basic "no failure" principle of organizational culture. 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.

4. 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. 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. The most important criteria for waterfall, agile and six sigma project management tools are determined by the result of IFCM, 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. Future research directions will focus on selecting the most appropriate provider for outsourcing a project that is supposed to be managed with waterfall, agile or lean six sigma project management methodologies.

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References

Asan, U., Soyer, A., and Bozdag, E., An interval type-2 fuzzy prioritization approach to project risk assessment, *J. Mult.-Valued Log. Soft Comput.,* vol. 26, no. 6, pp. 541-577, 2016.

Chatterjee, K., Zavadskas, E., Tamošaitienė J., Adhikary, K., and Kar, S., A hybrid MCDM technique for risk management in construction projects, *Symmetry*, vol. 10, no.2, Article no. 46, 2018.

Chen, Y. S., Wu, C., Chu, H. H., Lin, C. K., and Chuang, H. M., Analysis of performance measures in cloud-based ubiquitous SaaS CRM project systems, *J. Supercomput*., vol. 74, no. 3, pp. 1132-1156, 2018.

Cockburn, A., Selecting a project's methodology, *IEEE softw.*, vol. 17, no. 4, pp. 64-71, 2000.

Dogu, E., and Albayrak, Y.E. Criteria evaluation for pricing decisions in strategic marketing management using an intuitionistic cognitive map approach, *Soft Computing*, vol. 22, pp. 4989-5005, 2018.

Eshghi, A., Mousavi, S. M., and Mohagheghi V. A new interval type-2 fuzzy approach for analyzing and monitoring the performance of megaprojects based on earned value analysis, *Neural. Comput. Appl*., vol. 31, pp. 5109-5133, 2019.

Gijo, E.V. and Antony, J., Reducing patient waiting time in outpatient department using lean six sigma methodology, *Quality and Reliability Engineering International*, vol. 30, no. 8, pp. 1481-1491, 2014.

Iakovidis, D.K. and Papageorgiou, E. Intuitionistic fuzzy cognitive maps for medical decision making, *IEEE Transactions on Information Technology in Biomedicine,* vol. 15, pp. 100-107, 2011.

Joslin, R. and Müller, R., The impact of project methodologies on project success in different project environments, *Int. J. Manag. Proj*., vol. 9, no. 2, pp. 364-388, 2016.

Lei, H., Ganjeizadeh, F., Jayachandran, P.K., Ozcan, P.A., Statistical analysis of the effects of Scrum and Kanban on software development projects, *Robotics and Computer-Integrated Manufacturing,* vol. 43, pp. 59-67, 2017.

Snee, R.D. Lean Six Sigma–getting better all the time, *International Journal of Lean Six Sigma*, vol. 1, no. 1, pp. 9-29, 2000.

Totten, J., Critical Success Factors for Agile Project Management in Non-Software Related Product Development Teams", Ph.D. thesis, Western Michigan University, 2017.

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 Syst. Appl*., vol. 38, no. 5, pp. 5388-5405, 2011.

Wu, X.Y., Zhao, W.Y., Ma, T.S., and Yang, Z.Y., Improving the efficiency of highway construction project management using lean management, *Sustainability*, vol. 11, pp. 1-27, 2019.

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