SUCCESS FACTORS EVALUATION OF WATERFALL, AGILE AND LEAN SIX SIGMA PROJECT MANAGEMENT METHODOLOGIES USING FUZZY COGNITIVE MAP METHOD

(ŞELALE, ÇEVİK VE YALIN ALTI SİGMA PROJE YÖNETİMİ METODOLOJİLERİNİN BAŞARI FAKTÖRLERİNİN BULANIK BİLİŞSEL HARİTALAMA YÖNTEMİ İLE DEĞERLENDİRİLMESİ)

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LIST OF SYMBOLS

CM	:	Cognitive Map
FCM	:	Fuzzy Cognitive Map
MCDM	:	Multi-Criteria Decision-Making
AHP	:	Analytic Hierarchy Process
ANP	:	Analytic Network Process
DEMATEL	:	Decision-Making Trial and Evaluation Laboratory
TOPSIS	:	Technique for Order Preference by Similarity to Ideal Solution
BPO	:	Business Process Outsourcing
IT	:	Information Technology
CRM	:	Customer Relationship Management
CPM	:	Critical Path Method
LSS	:	Lean Six Sigma
ANFIS	:	Adaptive Neuro-Fuzzy Inference System Method
FAHP	:	Fuzzy Analytic Hierarchy Process
DANP	:	DEMATEL-based ANP
BPR	:	Business Process Reengineering
ARPM	:	Agile Reengineering Performance Model
D-CFPR	:	Consistent Fuzzy Preference Relation Using D-Number
D-MABAC	:	Multi-Attributive Border Approximation Area Comparison Using D-Number

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ABSTRACT

A project management methodology is essentially a set of guidelines and processes for project management. Methodology selection defines how you work and communicate. The Waterfall practice is the ancient methodology. As a response to handling the increasingly difficult nature of software development, Dr. Winston Royce first defined it in 1970. From that point forward, it has turned out to generally adopted, most highly in the software and management industry. Then, Agile, another software development centered project management methodology, arose as a reaction to the failure of Waterfall technique for managing complex projects. Even though Agile project management concepts had been in practice in the software and management industry for a longer time, it officially originated into being in 2001 when some IT delegates released the "Agile Manifesto". Lastly, Lean Six Sigma project management methodology compounds the strategies of Six Sigma and Lean. Process wastes are reduced and eliminated with the help of lean principles. Six Sigma emphases on variation - reduction in every process. Thus, Lean Six Sigma principle assist to enhance the productivity and quality of the process.

The right choice of project management methodology is one of the most important things to a project success. This thesis emphasizes in three project management methodologies 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. Primarily the literature review is conducted for the performance indicators of three project management methodologies. Therefore, It exposes the success factors that were issued in article, technical reports related to actual projects and research papers. Thus, evaluation criteria of these three project management methodologies are outlined through a deep literature survey and expertise of three top-line project managers. Fifteen success factors of project management methodologies are stated. The causal relations between pair of factors for each project management methodology are assigned by three different decision makers. Fuzzy cognitive map (FCM) technique is used to get the weight of each factor of each project management methodology. After the evaluation of factor's weights, the most important criteria are detected for waterfall, agile, and six sigma project management methodologies. Projects will be managed and finished successfully with prioritization of success factors.

ÖZET

Proje yönetimi metodolojisi bir projeyi yönetmek için temel prensipleri ve süreçleri tanımlayan rehber niteliğindedir. Proje yönetimi metodolojisi seçimi, proje kapsamında nasıl çalıştığınızı ve iletişim kurduğunuzu tanımlar.

Şelale proje yönetimi metodolojisi en eski metodolojidir. İlk kez 1970 yılında Dr. Winston Royce tarafından yazılım geliştirmenin gittikçe karmaşıklaşan doğasını yönetmeye cevap olarak doğmuş, yazılım ve hizmet sektörlerinde yaygın olarak kabul görmüştür. İkinci olarak, başka bir yazılım geliştirme odaklı proje yönetimi metodolojisi olan çevik proje yönetimi, şelale proje yönetiminin karmaşık projeleri yönetmedeki başarısızlığına cevap olarak ortaya çıkmıştır. Çevik proje yönetimi fikirleri yazılım ve hizmet sektöründe bir süredir kullanılmasına rağmen, birkaç bilgi teknolojileri temsilcisinin "Çevik Manifesto"yu yayınladığı 2001 yılında resmi olarak meydana çıkmıştır. Son olarak, yalın altı sigma proje yönetimi methodolojisi, Yalın ve Altı Sigma stratejilerinin birleşiminden doğmuştur. Yalın ilkeler, atıl süreçlerin azaltılmasına veya yok edilmesine yardımcı olmaktadır. Altı Sigma ise süreçteki varyasyonun azaltılmasına odaklanmaktadır. Böylece, Yalın Altı Sigma sürecin etkinliğini ve kalitesini arttırmaya yardımcı olmaktadır. Bir projenin başarılı olması için doğru proje yönetimi metodolojisini kullanmak kritik önem arz etmektedir.

Bu tezde, üç proje yönetimi metodolojisindeki başarı faktörlerinin çok boyutlu bir görünümünün resmedilmesi amaçlanmıştır. Waterfall, Agile ve Lean Six Sigma proje yönetimi metodolojilerinin başarı faktörlerinin ağırlıklarının ortaya konulması amaçlanmıştır. Çalışmada ilk olarak, üç proje yönetimi metodolojisinin başarı faktörlerini belirlemek için literatür araştırması yapılmıştır. Başarı faktörleri makalelerden, araştırma yazılarından ve gerçek projeler ile ilgili teknik raporlardan tespit edilmiştir. Tespit edilen başarı faktörleri üç üst düzey proje yöneticisinin de yardımı ile

teyit edilmiştir. Araştırmanın sonunda onbeş başarı faktörü belirlenmiştir. Her proje yönetimi metodolojisi için kriterler arasındaki nedensel ilişkiler üç farklı uzman tarafından belirlenmiştir. Bulanık bilişsel haritalama tekniği ile her bir proje yönetimi metodolojisinin faktör ağırlıkları belirlenmiştir. Faktör ağırlıklarının değerlendirilmesinden sonra, proje yönetimi metodolojilerinin en önemli kriterleri belirlenmiştir.

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). Constructions that have been made in the 3rd century BC are very fascinating and also astonish people not only its outlook but also overcoming such a difficult construction's management (Marić, 2017), which shows that project management is not a new thing. It is not a new idea; humans have been using this discipline (project management) unknowingly for many years (Manole and Grabara, 2016). Modern project management actually began to appear in the early 1900s, it can be observed on the development of Gantt charts (Marić, 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 birth 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.

The number of information technology and software engineering companies started to increase exponentially in the early 1990s. These companies relied on project management methodologies to advance in competition. Project management methodologies that are known and used at the present time were developed in the late 90's. Due to remarkable result, it can be say that project management methodologies have proved its effectiveness in aiding organization achieve organizational goals. Planning, budgeting and scheduling processes of companies that use one of the project management methodologies became more efficient and more effective consequently products that are produced became higher quality (Lei et al. 2017).

Many 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).

Although success factors definition of three project management methodologies necessitates a complex and ambiguous decision framework, very few studies in the literature have considered this complexity and uncertainty. However, there are positive as well as negative relations among project management methodologies success factors. Since FCM methodology considers two-way influences, it is an appropriate mathematical tool to evaluate success factors of three project management methodologies. Moreover, there is no work, which combines project management methodology performance and FCM methodology. Hence, this study will provide a novelty to the literature by employing an approach that has not been proposed by any scholar before.

The objective of this thesis 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. 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. These evaluation criteria will be useful and helpful to the top managers for making managerial decisions during the processes of many projects in the increasing technology.

The rest of this thesis is organized as follows. Section 2 outlines literature review on three project management methodologies named as waterfall, agile and lean six sigma, respectively. Section 3 explains the proposed methodology; section 4 gives application steps and then a numerical example in order to illustrate the robustness of the proposed approach. Conclusions are delineated in the section 5.

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2. LITERATURE REVIEW

Over the last decade, scholars have contributed to the selection of the right project management methodology by proposing several decision-making approaches. Cockburn (2000) outlined meaning of methodology and identified fundamentals for methodology selection. Lova and Tormos (2001) analyzed heuristic multi-project scheduling method of construction sector and evaluated this method's performance based on heuristic based on priority rules. Raffo (2005) evaluated project performance measure and estimated the performance of the project. Vidal et al. (2011) identified project complexity measure and evaluated project complexity. They utilized Delphi study and Analytic Hierarchy Process (AHP) method. In another study, Vidal et al. (2011) identified estimation project complexity measure using AHP method. Varajão and Cruz-Cunha (2013) selected the most appropriate project managers for projects and identified manager's capability. Petkovic et al. (2014) selected the most effective criterion and proposed suitable project management methodology regarding agile method. They utilized regression analysis and Adaptive Neuro-Fuzzy Inference System (ANFIS) method. Asan et al. (2014) proposed a model for risk assessment and risk prioritization of a project using type-2 fuzzy prioritization approach. Joslin and Müller (2015) identified success factors of project based on methodology elements and outlined the relation between methodologies and project success. García-Melón et al. (2015) suggested a decision support system for the ranking of a projects portfolio using Analytic Network Process (ANP) approach. Tabrizi et al. (2015) selected optimal project portfolio in a pharmaceutical company using Fuzzy Decision Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) method. Ghorabaee et al. (2015) sorted the alternatives and selected the most appropriate project. They utilized type-2 multicriteria optimization and compromise solution (T2F-VIKOR Fuzzy Vlse Kriterijumska Optimizacija Kompromisno Resenje which means multicriteria optimization and compromise solution, in Serbian) method. Serrador and Pinto (2015) evaluated agile project management methodology's success factors using correlation analysis. Prascevic et al. (2017) ranked and selected optimal resources in construction project using Fuzzy Analytic Hierarchy Process (FAHP). Chen et al. (2017) determined and evaluated the relevance of cloud Customer Relationship Management (CRM) project risk management and performance. They utilized DEMATEL-based ANP (DANP) and VIKOR methods. Lei et al. (2017) outlined project management performance measure and compared performance of the Scrum and Kanban methods regarding project management performance measures using statistical comparison. Petrillo et al. (2017) proposed a structure regarding agile project management to guide firms at decision-making process of optimizing the Business Process Reengineering (BPR). They utilized Agile Reengineering Performance Model (ARPM) method. Drury Grogan et al. (2017) outlined agile decision making to increase decision quality and evaluated four decision factors of agile decision-making. Chatterjee et al. (2018) categorized and prioritized risk factors of the construction projects. They utilized D numbers extended Consistent Fuzzy Preference Relation based ANP (D-CFPR) and D numbers based Multi-Attributive Border Approximation area Comparison (D-MABAC) methods.

Table 2.1: Literature review

Author(s)	**Year**	**Objective**	**Method(s)**	**Sectors**
Cockburn	2000	Outlining meaning of methodology and identifying fundamentals for methodology selection.	No mathematical method	Management
Lova and Tormos	2001	Analyzing heuristic multiproject scheduling method and evaluation this method’s performance.	Heuristic based on priority rules	Construction Sector
Raffo	2005	Estimating the performance of the project and evaluating project performance measure.	PROMPT (Project Management of Process Tradeoffs)	Management

Chow et al.	2007	Identifying critical success factors for agile software development projects by using quantitative approach.	Regression technique	Information Technology
Nonthaleerak et Hendry	2008	Identifying critical success factors for six sigma and investigating utilization at manufacturing and service sectors.	No mathematical method	Manufacturing
Misra et al.	2009	Outlining critical success factors for agile project methodologies	No mathematical method	Information Technology
Snee	2010	Assessing Lean Six Sigma to demonstrate its power	No mathematical method	Management
Vidal et al.	2011	Identifying project complexity measure and evaluate project complexity.	Delphi study AHP (Analytic Hierarchy Process)	Management
Vidal et al.	2011	Identifying and estimating project complexity measure	AHP (Analytic Hierarchy Process)	Management
Habidin and Yusof	2013	Outlining critical success factors for Lean Six Sigma Proejcts	SEM (Structural Equation Modeling) EFA (Exploratory Factor Analyses)	Manufacturing

			CFA (Confirmatory Factor Analysis) Reliability analysis	
Varajão and Cruz-Cunha	2013	Selection of the most appropriate project managers for projects, identifying manager's capability.	AHP (Analytic Hierarchy Process) ICB (IPMA Competence Baseline)	Management
Gijo and Antony	2014	Outlining the strength of LSS methodology	No mathematical method	Management
Petkovic et al.	2014	Selecting the most effective criterion and proposing suitable project management methodology regarding agile method.	Regression ANFIS (Adaptive Neuro-Fuzzy Inference System)	Management
Asan et al.	2014	Proposing a model for risk assessment and risk prioritization of a project	Type-2 fuzzy prioritization approach	Management
Ahimbisibwe et al.	2015	Proposing a model for critical success factor assessment based on a comparison agile and waterfall project management methodologies	Contingency fit model	Information Technology

Darwish and Rizk	2015	Identifying, classifying and evaluating critical success factors of agile software development projects	Data analysis	Information Technology
Joslin and Müller	2015	Identifying success factors of project based on methodology elements and outlining the relation between methodologies and project success.	No mathematical method	Management
García-Melón et al.	2015	Proposing a decision support system for the ranking of a projects portfolio.	ANP (Analytic Network Process)	Energy Sector
Noori	2015	Investigating critical performance factors of lean project by considering implementation in hospital	SEM (Structural Equation Modelling)	Health Sector
Tabrizi et al.	2015	Selection optimal project portfolio in a pharmaceutical company	Fuzzy DEMATEL Utility-based multi-choice goal programming technique	Health Sector
Ghorabaee et al.	2015	Sorting the alternatives and Selecting the most appropriate project.	T2F-VIKOR (type-2 fuzzy VIKOR)	Management
Serrador and Pinto	2015	Evaluating agile project management	Correlation analysis	Management

		methodology's success factors.		
Alhuraish et al.	2016	Identifying critical success factors both of lean and six sigma project management methodologies	Statistical analysis	Manufacturing
Manole and Grabara	2016	Outlining historical evolution of project management methodologies	No mathematical method	Management
Ahimbisibwe et al.	2017	Comparison of waterfall and agile methodologies 's critical success factors	No mathematical method	Information Technology
Aldahmash et al.	2017	Identifying critical success factors of agile software development	No mathematical method	Information Technology
Marić	2017	Comparison of project management methodologies	No mathematical method	Management
Prascevic et al.	2017	Ranking and selection optimal resources in construction project.	FAHP (Fuzzy Analytic Hierarchy Process)	Construction Sector
Chen et al.	2017	Determination and evaluation the relevance of cloud CRM project risk management and performance.	DANP (DEMATEL-based ANP) VIKOR	Information Technology
Lei et al.	2017	Outlining project management performance measure and comparing	Statistical Comparison	Information Technology

		performance of the Scrum and Kanban methods regarding project management performance measures.		
Micic	2017	Determining agile project methodology selection criteria	No mathematical method	Information Technology
Yadav et al.	2017	Determining and evaluating barriers of Lean Six Sigma project management methodology	Fuzzy AHP (Fuzzy Analytic Hierarchy Process)	Management
Petrillo et al.	2017	Proposing a structure regarding agile project management to guide firms at decision-making process of optimizing the BPR	ARPM (Agile Reengineering Performance Model)	Management
Totten	2017	Determining and defining critical success factors for agile project management	No mathematical method	Management
Drury Grogan et al.	2017	Outlining agile decision making to increase decision quality and evaluating 4 decision factors of agile decision-making.	No mathematical method	Management
Chatterjee et al.	2018	Categorizing and prioritization (evaluating) of risk factors of the construction projects.	D-CFPR based ANP (Consistent Fuzzy	Construction Sector

			Preference Relation using D-number) D-MABAC (D numbers based Multi-Attributive Border Approximation area Comparison)	
Yaghoobi	2018	Identifying, categorization and evaluating of critical success factors of software projects	AHP (Analytic Hierarchy Process)	Information Technology

3. PROPOSED METHODOLOGY: FUZZY COGNITIVE MAPS

3.1. Cognitive Maps

Cognitive maps (CMs) were initially introduced by Axelrod (1976) as a technique to explain decision aid systems in social and political sciences. CMs consist of directed arcs that enable to model causal links and relationships among concepts. There are a lot of types of CMs, named as weighted, signed, and functional graphs.

CMs can also be used for forecasting, R&D, strategic planning. The binary relationships (i.e., increase and decrease) are utilized in crisp (conventional) CM. CMs are the tools that are required for providing an engineering planning, by considering causalities, managing complexity, comparing the models with real cases, providing efficient evaluations (Ross, 2010).

3.1.1. Concepts and Causalities

CMs graphically defines a system regarding two main constituents: concepts and casue-and-effect relationships (causal relations). Nodes denotes the concepts, C_x, where x = 1,2,…,N. A cause concept term is represented as the term that is located at the origin of an arc, while an effect concept term is represented as the term which is at the endpoint of an arc. For example, an edge from the node C_h to the node C_i, proves that C_h is the cause term that influences C_i, that is the effect term. Figure 3.1 describes a simple CM that contains four concepts.

The arcs denotes the cause-and-effect relationships between concepts. For instance, an arrow from the node C_h to the node C_i, and that is negatively signed, indicates that C_h has a negative causal effect on C_i. Hence, a decrease in C_h causes to an increase in C_i. Likewise, an increase C_h causes a decrease in C_i (Ross, 2010).

3.1.2. Cycles and Paths

A path from a concept to another concept, from C_h to C_k, which is identified as *P(h,k)*, is an array of the concepts that are linked by edges from the first concept (C_h) to the final concept (C_k). A cycle refers to a path which has edge from the endpoint of the path to the origin of the first point (Ross, 2010).

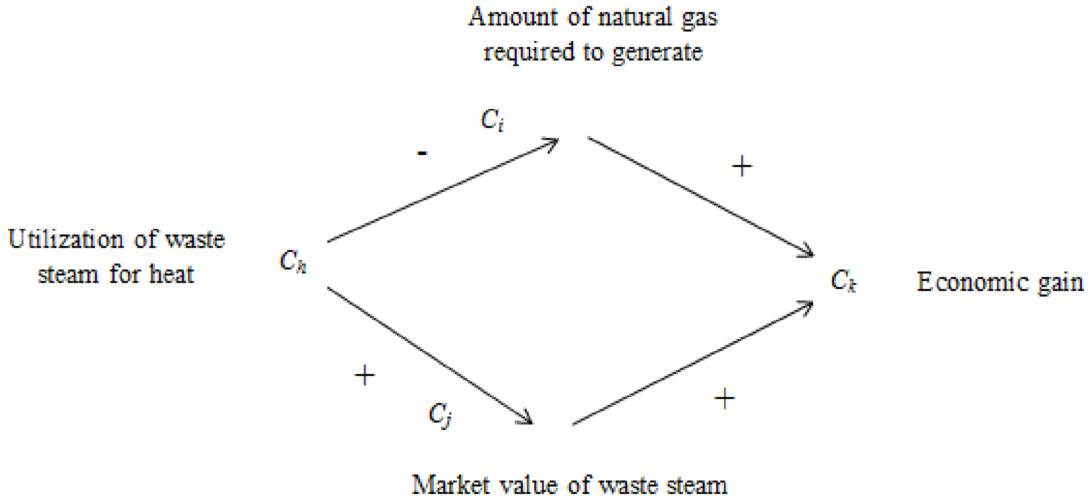

Figure 3.1: An example of a crisp CM for the usage of waste steam
(Kosko, 1986)

3.1.3. Indirect Influence

I(h,k), which represents the indirect influence of a route from the cause term C_h to the influence term C_k, denotes the product of the causality that construct the route from the cause term to the influence term (Axelrod, 1976). If a route has several negative edges, then the indirect influence is positive. However, if the route has both negative and positive edges, then the indirect influence is negative. Figure 3.1 indicates that the indirect influence of cause term C_h on the influence term C_k via route *P(h,i,k)* is negative and the indirect effect of the cause term *Ch* on the influence variable *Ck* via route *P(h,j,k)* is positive (Ross, 2010).

3.1.4. Total Influence

T(h,k), which denotes the total effect of cause term C_h on the influence variable C_k, is the sum of undirect influences of all the routes from the cause term to the influence term (Axelrod, 1976). If all the undirect influences are positive, then the total influence is positive. Likewise, if all the undirect influences are negative, then the total influence is negative. Besides, if some undirect influences are positive and some are negative, then the sum is not determinate (Kosko, 1986). A complex CM, which has a great number of concepts and paths, will be probably a candidate to be indeterminate. Figure 3.1 indicates that the total influence of cause term C_h to influence variable C_k is the summation of the undirect influence of C_h to C_k via routes *P(h,i,k)* and *P(h,j,k).* Since there are positive as well as negative influences along these paths, the total influence is indeterminate (Ross, 2010).

3.2. Basic Notions of Fuzzy Logic

3.2.1. Uncertainty and Information

Certain or deterministic information can be available only in a small portion of real world problems. The knowledge with no ignorance, vagueness, imprecision or chance, is not accessible in real life. Uncertain information, which can take many different forms, arises due to the complexity of problems, and the inability to measure adequately or lack of knowledge.

The type of uncertainty in a specific problem is crucial for scholars to select a suitable tool to imply the vagueness. Fuzzy sets are appropriate to obtain a mathematical framework in order to reveal uncertainty and fuzziness in decision systems (Ross, 2010).

3.2.2. Fuzzy Sets and Membership

Fuzzy sets enable a wider range of applicability than the classical sets. Basically, these sets help cope with issues in which the source of vagueness is the absence of determined factors of class membership rather than the presence of random variables (Zadeh, 1965).

The membership function involves the mathematical notation of membership in a set. The interval of the membership level of a variable in a fuzzy set is as follows.

$$\mu_{\tilde{A}}(x) \in [0,1] \tag{3.1}$$

where $\mu_{\tilde{A}}(x)$ refers to the membership level of variable x in fuzzy set $\tilde{A}$ (Ross, 2010).

Two example membership functions for a crisp set and a fuzzy set are given in Figure 3.2 and Figure 3.3, respectively.

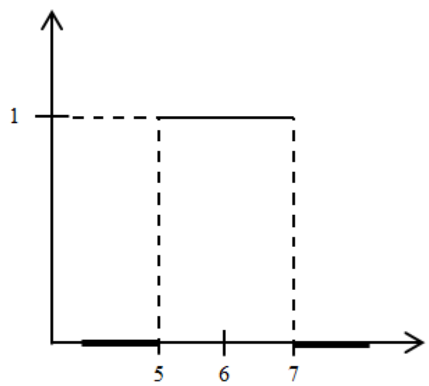

Figure 3.2: An example membership function for a crisp set (Ross, 2010)

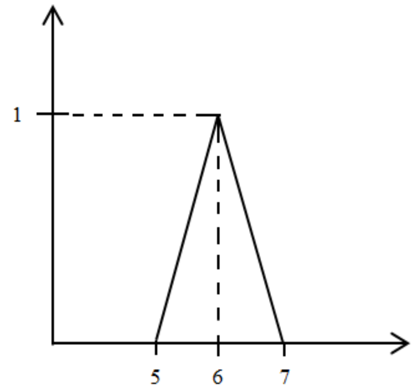

Figure 3.3: An example membership function for a fuzzy set (Ross, 2010)

3.2.2.1. Fuzzy Sets

A notation for a fuzzy set $\tilde{A}$, with the universe of discourse, *X*, which is finite and discrete, is as (Ross, 2010)

$$\tilde{A} = \left\{ \frac{\mu_{\tilde{A}}(x_1)}{x_1} + \frac{\mu_{\tilde{A}}(x_2)}{x_2} + \ldots \right\} = \left\{ \sum_i \frac{\mu_{\tilde{A}}(x_i)}{x_i} \right\} \tag{3.2}$$

A notation for a fuzzy set $\tilde{A}$, with the universe of discourse, X, which is continuous and infinite, is as (Ross, 2010):

$$\tilde{A} = \left\{ \int \frac{\mu_{\tilde{A}}(x)}{x} \right\} \tag{3.3}$$

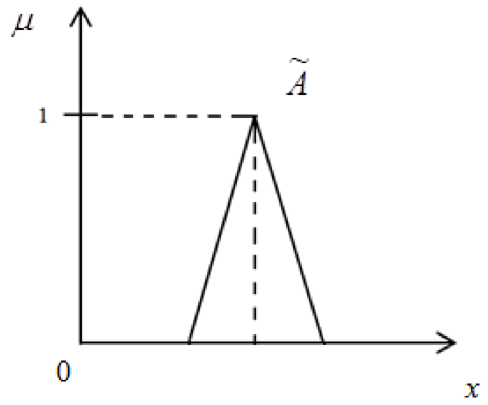

Figure 3.4: Membership function for fuzzy set $\tilde{A}$ (Ross, 2010)

3.2.2.1.1. Definitions of the Fuzzy Set

Definition 1:

A fuzzy set, whose membership function has at least one element x in the universe with a membership value that is equal to unity, is defined as a **normal fuzzy set** (Ross, 2010).

Definition 2:

A fuzzy set, whose membership function has no element x in the universe with a membership value that is equal to unity, is called as a **subnormal fuzzy set** (Ross, 2010).

Definition 3:

If the elements x, y and z in a fuzzy set $\tilde{A}$ has a relation such that $x < y < z$, which implies that $\mu_{\tilde{A}}(y) \geq \min[\mu_{\tilde{A}}(x), \mu_{\tilde{A}}(z)]$, then $\tilde{A}$ is a **convex fuzzy set** (Ross, 2010).

Definition 4:

The maximum value of a membership function is said to be the height of a fuzzy set $\tilde{A}$, which is denoted by the following formulation (Ross, 2010).

$$hgt(\tilde{A}) = \max\{\mu_{\tilde{A}}(x)\} \tag{3.4}$$

If $\tilde{A}$ is a convex normal fuzzy set described on the real line, then $\tilde{A}$ is said to be a fuzzy number (Ross, 2010).

3.2.2.2. Definitions of the Membership Function

Definition 1:

The core of a membership function contains elements *x* such that $\mu_{\tilde{A}}(x) = 1$ (Ross, 2010).

Definition 2:

The support of a membership function involves elements *x* such that $\mu_{\tilde{A}}(x) > 0$ (Ross, 2010).

Definition 3:

The boundaries of a membership function consists of elements *x* such that $0 < \mu_{\tilde{A}}(x) < 1$ (Ross, 2010).

Definition 4:

The crossover points of a membership function includes elements *x* such that $\mu_{\tilde{A}}(x) = 0.5$ (Ross, 2010).

3.2.3. Defuzzification

Defuzzification denotes the transformation of a fuzzy number to a crisp number (Ross, 2010).

3.2.3.1. Defuzzification to Crisp Sets

Let $\tilde{A}$ is a fuzzy set, A_λ is a lambda-cut set, where $0 \le \lambda \le 1$. A_λ, which is called as the *lambda*(λ)-*cut* (or *alpha-cut*), is a crisp set of the fuzzy set $\tilde{A}$, where $A_\lambda = \{x | \mu_{\tilde{A}}(x) \ge \lambda\}$ (Ross, 2010).

3.2.3.2. Defuzzification to Scalars

There exist various defuzzification methods that are proposed in the literature. Ross (2010) considers four main methods whose formulations are given as follows.

- ***Max membership principle:***

$$\mu_{\tilde{A}}(z^*) \geq \mu_{\tilde{A}}(z), \qquad \text{for all } z \in Z, \tag{3.5}$$

where z^* is the defuzzified value.

- ***Center of gravity (COG):***

$$z^* = \frac{\int \mu_{\tilde{A}}(z).z \quad dz}{\int \mu_{\tilde{A}}(z)\,dz}, \tag{3.6}$$

where $\int$ refers to an algebraic integration.

- ***Weighted average method:***

$$z^* = \frac{\sum \mu_{\tilde{A}}(\bar{z}).\bar{z}}{\sum \mu_{\tilde{A}}(\bar{z})}, \tag{3.7}$$

where $\sum$ represents the algebraic sum and $\bar{z}$ is the center of gravity of each symmetric membership function.

- ***Mean max membership principle:***

$$z^* = \frac{a+b}{2} \tag{4.8}$$

where *a* and *b* are the points that are located on the plateau.

3.3. Fuzzy Cognitive Maps

3.3.1. Indeterminacy

A crisp CM, which is non determinate, may be modeled by revealing a numerical weighting, however, it needs computational operations (Kosko, 1986). If the causal edges are positively or negatively weighted, the undirect effect refers to the product of the weights in the corresponding route, and the total influence is the sum of these products. This weighting concept not also solves the problem of indeterminacy; yet also needs a more sensitive causal discrimination, which may be impossible for experts who are to construct the CM. Forcing them to construct CM with crisp numbers leads insufficient information, different numbers from different experts or different numbers from the same expert on different timeline. However, cause-and-effect relationships can be expressed by linguistic terms rather than numerical variables by developing FCM tool (Ross, 2010).

3.3.2. Methodology of FCM

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 (Kosko, 1986). Hereafter, Taber and Kosko (Kosko, 1986; Taber, 1994) extended the method and incorporated fuzzy numbers or linguistic terms for revealing the causal relationships among concepts in FCM. Concepts and weighted arcs are the components of FCM. Arcs are signed to explain the direction of causal links: whether the causal link is positive, negative or null, and connect the nodes through which causal relationships among the factors are produced (Büyükavcu et al., 2016).

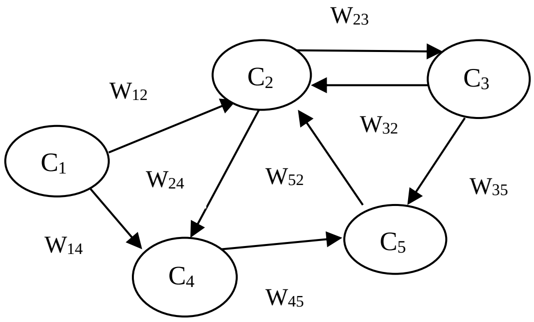

Figure 3.5: Graphical representation of FCM (Büyükavcu et al., 2016)

$C = \{C_1, C_2, ..., C_n\}$ is the representation of concepts, arcs (C_j, C_i) demonstrate how concept C_j causes concept C_i, and are utilized for cause-and-effect relationships between concepts. The weights of causality links range in the interval [-1,1] or can be represented with linguistic variables such as “negatively weak”, “zero”, “positively weak”, etc. Figure 3.5 and Figure 3.6 delineate the graphical representation and application steps of a FCM, respectively.

Figure 3.6: Application steps of FCM (Büyükavcu et al., 2016)

Each concept’s value is computed by taking into account the influence of the other concepts on the evaluated concept, by running the following iterative formulation of FCM.

$$A_i^{(k+1)} = f\left(A_i^{(k)} + \sum_{\substack{j \neq i \\ j=1}}^{N} A_j^{(k)} w_{ji}\right) \tag{3.9}$$

where $A_i^{(k)}$ is the value of concept Ci at kth iteration, w_{ji} is the weight of the connection from C_j to C_i, and f is a threshold function. This formulation is run until the system will be stable, in other words, there will be no change on concepts’ values (Büyükavcu et al., 2016).

4. APPLICATION

The target of this thesis is to utilize FCM technique so as to uncover the success factors of three project management methodologies named as waterfall, agile and lean six sigma. Inıtıally, 15 success factors of project management are selected through expert opinions and literature review. After that, the causal relations between pair of factors are determined by decision makers for each project management methodology. As a final point, as indicated by the weight of each factor of each project management methodology, the most significant criteria are indicated for waterfall, agile, and six sigma project management methodologies. These assessment criteria will be valuable and guiding to the executive managers for settling on administrative choices amid the processes of projects in the increasing technology and innovation era.

Performance criteria for three project management methodologies are given in Table 4.1. The application steps are given in Figure 4.1.

Table 4.1: Performance criteria for three 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

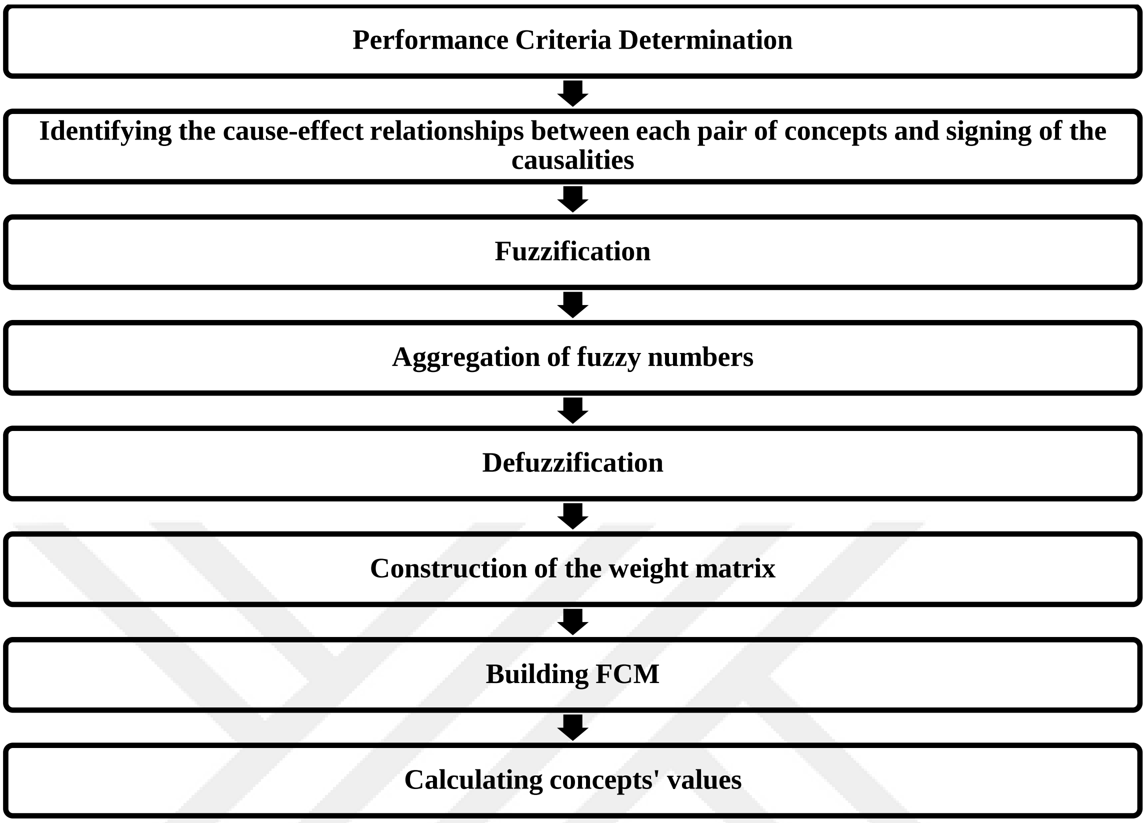

Figure 4.1: Application steps of the study

The matrix that is sent to the decision makers to be filled is given in Table 4.1. Experts decide initially the power of causalities by using linguistic variables; subsequently linguistic variables are mapped to fuzzy numbers. In this study, nine linguistic terms are utilized such as negatively very strong (nvs), negatively strong (ns), negatively medium (nm), negatively weak (nw), zero (z), positively weak (pw), positively medium (pm), positively strong (ps), positively very strong (pvs). The corresponding membership functions for these linguistic variables are reported in Figure 4.2.

They are referred as: $\mu_{nvs}, \mu_{ns}, \mu_{nm}, \mu_{nw}, \mu_{z}, \mu_{pw}, \mu_{pm}, \mu_{pm}, \mu_{ps}, \mu_{pvs}$.

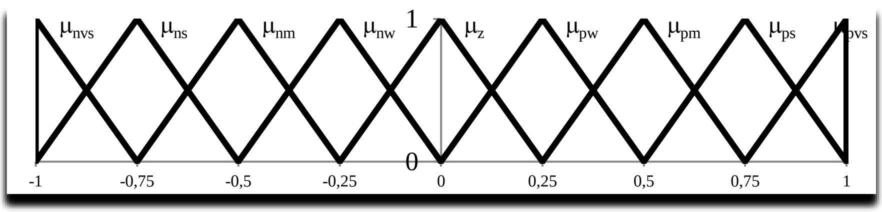

Figure 4.2: The nine membership functions corresponding to each fuzzy term of influence

Table 4.2: The copy of the matrix that is sent to the experts

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**
C1															
C2															
C3															
C4															
C5															
C6															
C7															
C8															
C9															
C10															
C11															
C12															
C13															
C14															
C15															

4.1. Waterfall

In this section of the thesis, importance degrees of performance factors of waterfall project management methodology are determined. Initially, sign matrices are obtained by collecting data from Expert 1, Expert 2, and Expert 3. They are shown in Table 4.3, Table 4.4 and Table 4.5 respectively.

Table 4.3: The matrix of sign according to the Expert 1 (Waterfall)

	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										+					
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}										-	-				

Table 4.4: The matrix of sign according to the Expert 2 (Waterfall)

	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										+					
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}										-	-				

Table 4.5: The matrix of sign according to the Expert 3 (Waterfall)

	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										+					
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}										-	-				

After obtaining sign matrices, power of cause-and-effect relationships between pair of factors are determined by the decision makers as in Table 4.6, Table 4.7, and Table 4.8.

Table 4.6: The matrix of power of causalities by using linguistic variables according to the Expert 1 (Waterfall)

	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	pm	z	z	z	z	z
C_2	pw	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	pvs	z	z	z	nvs
C_4	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	pm	z	z
C_6	z	z	z	z	z	z	pw	z	ps	z	pm	z	z	z	z
C_7	z	z	z	z	z	z	z	z	z	z	ps	z	z	z	z
C_8	z	z	z	z	pw	z	pw	z	ps	z	ps	z	z	ps	z
C_9	z	z	z	z	z	z	ps	z	z	z	z	z	z	z	z
C_{10}	z	z	z	z	z	z	z	z	z	z	ps	z	ps	z	ns
C_{11}	z	z	z	z	z	z	z	z	z	z	z	z	z	z	nvs
C_{12}	z	z	z	z	z	z	z	z	z	ps	z	z	z	z	z
C_{13}	z	z	z	z	pm	z	z	z	z	z	z	z	z	z	z
C_{14}	ps	z	pw	pw	pm	z	z	z	z	ps	pw	z	pm	z	z
C_{15}	z	z	z	z	z	z	z	z	z	nm	ns	z	z	z	z

Table 4.7: The matrix of power of causalities by using linguistic variables according to the Expert 2 (Waterfall)

	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	pvs	z	z	z	z	z
C_2	pm	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	pvs	z	z	z	nvs
C_4	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	pvs	z	z
C_6	z	z	z	z	z	z	pm	z	pvs	z	pvs	z	z	z	z
C_7	z	z	z	z	z	z	z	z	z	z	pm	z	z	z	z
C_8	z	z	z	z	pm	z	pm	z	pm	z	pm	z	z	pm	z
C_9	z	z	z	z	z	z	pm	z	z	z	z	z	z	z	z
C_{10}	z	z	z	z	z	z	z	z	z	z	pvs	z	pvs	z	nm
C_{11}	z	z	z	z	z	z	z	z	z	z	z	z	z	z	nvs
C_{12}	z	z	z	z	z	z	z	z	z	pm	z	z	z	z	z
C_{13}	z	z	z	z	pvs	z	z	z	z	z	z	z	z	z	z
C_{14}	pm	z	pm	pm	ps	z	z	z	z	pvs	pm	z	pvs	z	z
C_{15}	z	z	z	z	z	z	z	z	z	ns	nvs	z	z	z	z

Table 4.8: The matrix of power of causalities by using linguistic variables according to the Expert 3 (Waterfall)

	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	ps	z	z	z	z	z
C_2	pw	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	pvs	z	z	z	nvs
C_4	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	ps	z	z
C_6	z	z	z	z	z	z	pw	z	ps	z	ps	z	z	z	z
C_7	z	z	z	z	z	z	z	z	z	z	pw	z	z	z	z
C_8	z	z	z	z	pw	z	pw	z	pw	z	pw	z	z	pw	z
C_9	z	z	z	z	z	z	pw	z	z	z	z	z	z	z	z
C_{10}	z	z	z	z	z	z	z	z	z	z	ps	z	ps	z	nw
C_{11}	z	z	z	z	z	z	z	z	z	z	z	z	z	z	ns
C_{12}	z	z	z	z	z	z	z	z	z	pw	z	z	z	z	z
C_{13}	z	z	z	z	ps	z	z	z	z	z	z	z	z	z	z
C_{14}	pw	z	pw	pw	ps	z	z	z	z	ps	pw	z	pvs	z	z
C_{15}	z	z	z	z	z	z	z	z	z	ns	ns	z	z	z	z

The linguistic data are aggregated using MAX method, and then defuzzified by Center of Gravity (COG) technique utilizing MATLAB Fuzzy Toolbox, and then weight matrix is obtained as given in Table 4.9. Afterwards, by running the iterative formulation of FCM until the system wil be stabilized, concepts' values in other words the values of performance indicators are identified. Concepts' values of waterfall project management methodology performance are provided in Table 4.10.

Table 4.9: The weight matrix according to three experts' opinions (Waterfall)

	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 4.10: The concepts' values of waterfall project management methodology performance

Label	**Concept**	**Concept's value**
C_{11}	Clear requirements and specifications	0.99897
C_{13}	Structured project procedure and progress reporting	0.99028
C_{10}	Level of project planning	0.98442
C_5	Monitoring and controlling	0.95347
C_7	Project team's ability to react to change	0.78979
C_1	Top-level management support	0.73484
C_3	Clear objectives and goals	0.67271
C_4	Customer participation	0.67271
C_9	Self-organizing and collaborating team	0.50321
C_{14}	Effective project manager skills	0.37610
C_2	Organizational culture	0.03868
C_6	Communication between team members	0.03868
C_8	Project team's general expertise	0.03868
C_{12}	Understanding the tools and techniques	0.03868
C_{15}	Project complexity	-0.99404

4.2. Agile

In this section of the thesis, importance degrees of performance factors of agile project management methodology are determined. Initially, sign matrices are obtained by collecting data from Expert 1, Expert 2, and Expert 3 as in Table 4.11. Table 4.12, and Table 4.13, respectively.

Table 4.11: The matrix of sign according to the Expert 1 (Agile)

	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															
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}					-		-			-					

Table 4.12: The matrix of sign according to the Expert 2 (Agile)

	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															
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}					-		-			-					

Table 4.13: The matrix of sign according to the Expert 3 (Agile)

	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															
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}					-		-			-					

After obtaining sign matrices, power of cause-and-effect relationships between pair of factors are determined by the decision makers as in Table 4.14, Table 4.15, and Table 4.16.

Table 4.14: The matrix of power of causalities by using linguistic variables according to the Expert 1 (Agile)

	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
C_2	z	z	z	pm	z	pm	z	ps	ps	z	z	z	z	pw	z
C_3	z	z	z	z	z	z	z	z	z	z	z	z	z	z	ns
C_4	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	pw	z	ns
C_6	z	z	z	z	z	z	ps	z	pvs	z	z	z	z	z	z
C_7	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z
C_8	z	z	z	z	z	z	pm	z	z	z	z	z	z	z	z
C_9	z	z	z	ps	z	ps	pm	z	z	z	z	z	z	z	z
C_{10}	z	z	z	z	z	z	z	z	z	z	z	z	z	z	nm
C_{11}	z	z	z	z	z	z	z	z	z	z	z	z	z	z	nm
C_{12}	z	z	z	z	z	z	z	z	z	z	z	z	pw	z	z
C_{13}	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z
C_{14}	pw	z	z	pw	z	pw	z	z	z	z	z	z	z	z	z
C_{15}	z	z	z	z	nm	z	nm	z	z	ns	z	z	z	z	z

Table 4.15: The matrix of power of causalities by using linguistic variables according to the Expert 2 (Agile)

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

Table 4.16: The matrix of power of causalities by using linguistic variables according to the Expert 3 (Agile)

	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
C_2	z	z	z	pvs	z	pvs	z	pw	ps	z	z	z	z	pw	z
C_3	z	z	z	z	z	z	z	z	z	z	z	z	z	z	ns
C_4	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	pw	z	nw
C_6	z	z	z	z	z	z	ps	z	pvs	z	z	z	z	z	z
C_7	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z
C_8	z	z	z	z	z	z	ps	z	z	z	z	z	z	z	z
C_9	z	z	z	ps	z	ps	ps	z	z	z	z	z	z	z	z
C_{10}	z	z	z	z	z	z	z	z	z	z	z	z	z	z	ns
C_{11}	z	z	z	z	z	z	z	z	z	z	z	z	z	z	nvs
C_{12}	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	z	z	z
C_{14}	pw	z	z	pw	z	pw	z	z	z	z	z	z	z	z	z
C_{15}	z	z	z	z	ns	z	nw	z	z	nw	z	z	z	z	z

The linguistic data are aggregated using MAX method, and then defuzzified by Center of Gravity (COG) technique utilizing MATLAB Fuzzy Toolbox, and then weight matrix is obtained as given in Table 4.17. Afterwards, by running the iterative formulation of FCM until the system wil be stabilized, concepts' values in other words the values of performance indicators are identified. Concepts' values of agile project management methodology performance are provided in Table 4.18.

Table 4.17: The weight matrix according to three experts' opinions (Agile)

	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 4.18: The concepts' values of agile project management methodology performance

Label	**Concept**	**Concept's value**
C_7	Project team's ability to react to change	0.99631
C_4	Customer participation	0.95788
C_6	Communication between team members	0.95788
C_9	Self-organizing and collaborating team	0.95554
C_5	Monitoring and controlling	0.90877
C_{10}	Level of project planning	0.87695
C_{13}	Structured project procedure and progress reporting	0.82804
C_1	Top-level management support	0.68650
C_8	Project team's general expertise	0.44262
C_{14}	Effective project manager skills	0.40700
C_2	Organizational culture	0.06525
C_3	Clear objectives and goals	0.06525
C_{11}	Clear requirements and specifications	0.06525
C_{12}	Understanding the tools and techniques	0.06525
C_{15}	Project complexity	-0.97089

4.3. Lean 6σ

In this section of the thesis, importance degrees of performance factors of lean 6σ project management methodology are determined. Initially, sign matrices are obtained by collecting data from Expert 1, Expert 2, and Expert 3 as in Table 4.19, Table 4.20, and Table 4.21 respectively.

Table 4.19: The matrix of sign according to the Expert 1 (Lean 6σ)

	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					+					+			+		
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}										-					

Table 4.20: The matrix of sign according to the Expert 2 (Lean 6σ)

	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					+					+			+		
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}										-					

Table 4.21: The matrix of sign according to the Expert 3 (Lean 6σ)

	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					+								+		
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}															

After obtaining sign matrices, power of cause-and-effect relationships between pair of factors are determined by the decision makers as in Table 4.22, Table 4.23, and Table 4.24.

Table 4.22: The matrix of power of causalities by using linguistic variables according to the Expert 1 (Lean 6σ)

	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	pw	z	z	z	z	pw	z	z	ps	z	z
C_2	z	z	z	z	z	z	z	ps	z	pw	z	z	z	z	z
C_3	z	z	z	z	z	z	z	z	z	z	ps	z	z	z	nw
C_4	z	pw	z	z	z	z	z	z	z	z	z	z	z	z	z
C_5	pw	z	z	z	z	z	z	z	z	z	pw	z	pm	z	z
C_6	z	pm	z	z	z	z	pw	pw	pw	z	z	ps	ps	z	z
C_7	z	ps	z	z	z	z	z	z	z	z	z	z	z	z	z
C_8	z	ps	z	z	z	z	z	z	z	z	z	pm	z	ps	z
C_9	z	pm	z	z	z	pw	z	pm	z	z	z	ps	z	z	z
C_{10}	z	z	z	z	pw	z	z	z	z	z	z	z	z	z	nw
C_{11}	z	z	ps	z	pw	z	z	z	z	z	z	z	z	z	z
C_{12}	z	pw	z	z	z	z	z	pm	z	z	z	z	z	z	z
C_{13}	z	pw	pw	z	z	z	z	pw	z	z	z	z	z	pm	nw
C_{14}	z	pw	z	z	z	z	z	z	z	z	z	z	pm	z	z
C_{15}	z	z	z	z	z	z	z	z	z	nw	z	z	z	z	z

Table 4.23: The matrix of power of causalities by using linguistic variables according to the Expert 2 (Lean 6σ)

	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	pm	z	z	z	z	pm	z	z	pm	z	z
C_2	z	z	z	z	z	z	z	pm	z	pm	z	z	z	z	z
C_3	z	z	z	z	z	z	z	z	z	z	pm	z	z	z	nm
C_4	z	pw	z	z	z	z	z	z	z	z	z	z	z	z	z
C_5	pm	z	z	z	z	z	z	z	z	z	pw	z	pvs	z	z
C_6	z	pvs	z	z	z	z	pw	pm	pw	z	z	pm	pm	z	z
C_7	z	pm	z	z	z	z	z	z	z	z	z	z	z	z	z
C_8	z	pm	z	z	z	z	z	z	z	z	z	pvs	z	pw	z
C_9	z	pvs	z	z	z	pw	z	pvs	z	z	z	pm	z	z	z
C_{10}	z	z	z	z	pw	z	z	z	z	z	z	z	z	z	nm
C_{11}	z	z	pm	z	pm	z	z	z	z	z	z	z	z	z	z
C_{12}	z	pm	z	z	z	z	z	pvs	z	z	z	z	z	z	z
C_{13}	z	pm	pm	z	z	z	z	pm	z	z	z	z	z	ps	nm
C_{14}	z	pm	z	z	z	z	z	z	z	z	z	z	pvs	z	z
C_{15}	z	z	z	z	z	z	z	z	z	nm	z	z	z	z	z

Table 4.24: The matrix of power of causalities by using linguistic variables according to the Expert 3 (Lean 6σ)

	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	pw	z	z	z	z	z	z	z	pw	z	z
C_2	z	z	z	z	z	z	z	pw	z	pw	z	z	z	z	z
C_3	z	z	z	z	z	z	z	z	z	z	pw	z	z	z	nw
C_4	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z
C_5	pw	z	z	z	z	z	z	z	z	z	z	z	ps	z	z
C_6	z	pvs	z	z	z	z	z	pw	z	z	z	pw	pw	z	z
C_7	z	pw	z	z	z	z	z	z	z	z	z	z	z	z	z
C_8	z	pw	z	z	z	z	z	z	z	z	z	pvs	z	pw	z
C_9	z	pvs	z	z	z	z	z	pvs	z	z	z	pw	z	z	z
C_{10}	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z
C_{11}	z	z	pw	z	z	z	z	z	z	z	z	z	z	z	z
C_{12}	z	pw	z	z	z	z	z	pvs	z	z	z	z	z	z	z
C_{13}	z	pw	z	z	z	z	z	pw	z	z	z	z	z	ps	z
C_{14}	z	pw	z	z	z	z	z	z	z	z	z	z	pvs	z	z
C_{15}	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z

The linguistic data are aggregated using MAX method, and then defuzzified by Center of Gravity (COG) technique utilizing MATLAB Fuzzy Toolbox, and then weight matrix is obtained as given in Table 4.25. Afterwards, by running the iterative formulation of FCM until the system wil be stabilized, concepts' values in other words the values of performance indicators are identified. Concepts' values of lean 6σ project management methodology performance are provided in Table 4.26.

Table 4.25: The weight matrix according to three experts' opinions (Lean 6σ)

	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 4.26: The concepts' values of lean 6σ project management methodology performance

Label	Concept	Concept's value
C_2	Organizational culture	0.99896
C_8	Project team's general expertise	0.99583
C_{13}	Structured project procedure and progress reporting	0.99436
C_{12}	Understanding the tools and techniques	0.97495
C_{14}	Effective project manager skills	0.97013
C_{10}	Level of project planning	0.94310
C_3	Clear objectives and goals	0.92536
C_5	Monitoring and controlling	0.91871
C_{11}	Clear requirements and specifications	0.90229
C_1	Top-level management support	0.82586
C_6	Communication between team members	0.56104
C_7	Project team's ability to react to change	0.56104
C_9	Self-organizing and collaborating team	0.56104
C_4	Customer participation	0.26164
C_{15}	Project complexity	-0.94478

Table 4.27: The comparison of concepts' values of three project management methodologies

Label	Concept	Waterfall Concept's value	Waterfall Rank	Agile Concept's value	Agile Rank	Lean 6σ Concept's value	Lean 6σ Rank
C_1	Top-level management support	0.73484	7	0.68650	9	0.82586	11
C_2	Organizational culture	0.03868	12	0.06525	12	0.99896	1
C_3	Clear objectives and goals	0.67271	8	0.06525	13	0.92536	8
C_4	Customer participation	0.67271	9	0.95788	3	0.26164	15
C_5	Monitoring and controlling	0.95347	5	0.90877	6	0.91871	9
C_6	Communication between team members	0.03868	13	0.95788	4	0.56104	12
C_7	Project team's ability to react to change	0.78979	6	0.99631	1	0.56104	13
C_8	Project team's general expertise	0.03868	14	0.44262	10	0.99583	2
C_9	Self-organizing and collaborating team	0.50321	10	0.95554	5	0.56104	14
C_{10}	Level of project planning	0.98442	4	0.87695	7	0.94310	7
C_{11}	Clear requirements and specifications	0.99897	1	0.06525	14	0.90229	10
C_{12}	Understanding the tools and techniques	0.03868	15	0.06525	15	0.97495	4
C_{13}	Structured project procedure and progress reporting	0.99028	3	0.82804	8	0.99436	3
C_{14}	Effective project manager skills	0.37610	11	0.40700	11	0.97013	5
C_{15}	Project complexity	-0.99404	2	-0.97089	2	-0.94478	6

5. CONCLUSION

Project management methodologies was started to practice only since mid-1900s by organizations and firms; though, notion of project management methodology has been utilised for a very long time in practical terms.
Classical era's constructions are very astonishing and difficult to construct. Thanks to the project management idea that had been used unintentionally, constructions of these buildings had been made easily. It can be understood that project management notion was not a new knowledge, it had formed building block of modern project management idea. The project management methodologies was mostly utilized by navy, defense and space industries at 1900s. In the mid 1900s, the most popular project management methodology was the waterfall model, thanks to this methodology Neil Armstrong was the first person to set foot on the moon.

In the early 1990s, the number of IT and software engineering companies began to grow incrementally and these companies started to use project management methodologies to get ahead of their rivals. These companies success shows us that project management methodologies are more than usefull, they become essential. Companies accomplish their goals; they are getting more efficients and productives due to the project management methodologies.

Our aim is to weight performance indicators of project management methodologies that are most widely used nowadays, named as waterfall, agile and lean six sigma. Firstly, fifteen performance indicators of project management methodologies are determined through expert opinions and deep literature survey. Then, causal relations between pair of factors for each project management methodology are assigned by three decision makers. Lastly, weights that belong each factor of each project management methodology are calculated by employing fuzzy cognitive map (FCM) technique. The most important criteria for waterfall, agile and six sigma project management tools are determined by the result of FCM technique. 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

The waterfall weight matrix shows us that there are 30 connections in total. Five factors, named *monitoring and controlling*, *level of project planning*, *clear requirements and specifications*, *structured project procedure and progress reporting*, *project complexity* are the most important concepts. The other six factors, *named top-level management support, clear objectives and goals, customer participation, project team's ability to react to change, self-organizing and collaborating team, effective project manager skills* are seen as semi-important concepts. The last four factors, named *organizational culture, communication between team members, project team's general expertise, understanding the tools and techniques* are less important concepts and FCM shows that they have a low degree of power.
The agile weight matrix shows us that there are 23 connections in total. Six factors, named *customer participation, monitoring and controlling, communication between team members, project team's ability to react to change, self-organizing and collaborating team, project complexity* are the most important concepts. The other five factors, named *top-level management support, project team's general expertise, level of project planning, structured project procedure and progress reporting, effective project manager skills* are seen as semi-important concepts. The last four factors, named *clear requirements and specifications, clear objectives and goals, organizational culture, understanding the tools and techniques* are less important concepts and FCM shows that they have a low degree of power.

The waterfall weight matrix shows us that there are 30 connections in total. Five factors, named *organizational culture, project team's general expertise, structured project procedure and progress reporting, understanding the tools and techniques, effective project manager skills* are the most important concepts. The other six factors, named *level of project planning, clear objectives and goals, monitoring and controlling, clear requirements and specifications, top-level management support, project complexity* are seen as semi-important concepts. The last four factors, named *customer participation, project team's ability to react to change, self-organizing and collaborating team, communication between team members* are less important concepts and FCM shows that they have a low degree of power.

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7. BIOGRAPHICAL SKETCH

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