A Multi-Criteria Decision-Making Framework for Software Project Management Tool Selection

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ABSTRACT

Project management tools are critical for managing software projects, decreasing costs, accelerating timelines, and using available resources effectively. However, project managers find it very tedious to choose a suitable software project management (SPM) tool from available tools in the market. The appropriateness of the SPM tool depends on the nature of the software project being developed – an SPM tool suitable for a large-scale software project may not be appropriate for small-scale projects. However, due to the complexities of the software projects and the development conditions, the selection of an SPM tool is often biased by personal preferences or marketing publicities which may lead to inefficiencies in SPM and consequently, lead to higher cost and lower quality of end product. In this work, we present a decision support framework for SPM tool selection. The proposed system develops a set of selection criteria based on an analytic network process (ANP). To demonstrate the internal working of the proposed framework, we put forward an example of the tool selection problem using the proposed system. Furthermore, the proposed system can be used as is for SPM tool selection for other than software projects.

KEYWORDS

Software selection, SPM tools selection, Analytic network process

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1 INTRODUCTION

Software Project Management (SPM) is an umbrella term used to refer to the systematic execution of processes such as planning, monitoring, staffing, and leading software projects to minimize the cost of software production while attaining high quality end-product [13]. According to the Project Management Institute, project management is to apply knowledge, experience, tools, skills, and well-established techniques during software project development to attain the desired goals. Software projects are very complex in nature and therefore, require a lot of human and other organizational resources [11]. Hence, one of the main aims of SPM is to run all project activities according to the initial plan in terms of budget and schedule. Due to the varying nature of software projects in terms of size and complexity, the success of all software developing firms depends on the efficient yet effective management of their software projects. In other words, the lack of effective SPM skills, experience, tools, and techniques may lead to the failure of software projects to meet their requirements.

Project managers need to choose a suitable set of tools in the marketplace to improve productivity and avoid violating time and budget constraints [2]. One of the key factors behind the failure of software projects is time delays due to low productivity during software development which is always a great challenge for software project managers. To cope with the said issue, SPM tools have been developed to automate all the SPM activities during the software project life-cycle [15]. Moreover, these SPM tools are being used extensively nowadays by software project managers to manage their projects more efficiently and effectively. However, the successful execution of SPM activities to avoid project failures significantly depends on the selection of a suitable SPM tool. Moreover, it is even more important for software project managers to consider the selection of tools that contain advanced features such as managing parallel software projects in addition to achieving basic project goals for individual projects separately [20].

Researchers discuss and evaluate different SPM tools in the existing literature based on the features related to enhancing productivity and other SPM activities [20]. Microsoft Project, Primavera, Assebla, JIRA, Asana, Trello, and Ganttproject are some of the well-known project management tools [15][20][11]. The aforementioned tools encapsulate the basic functionalities such as task management, document sharing, report generation, calendar and contacts list, time-tracking, requirements traceability, managing resources, cost estimation, collaboration features, and integration of multiple projects [15]. In addition to the said core features, the SPM tools provide easy-to-use features such as risk assessment, earned-value analysis, critical-path analysis, and email integration [13]. These tools have different advanced features, which makes them more appropriate for some projects compared to others. Hence, one tool that can work well for some projects may not be very effective for others. Hence, it is very important to keep in mind several factors such as the size, nature, and complexity of the software project while choosing a SPM tool, as it significantly affects the quality and productivity during the life-cycle of a software project.

Existing literature presents a plethora of decision-making frameworks for the selection of the most suitable SPM tool [14]. Multi-Criteria Decision-Making (MCDM) is a set of concepts, procedures, and techniques used to make complex SPM tool selection decisions based on multiple criteria in a structured, well-organized and systematic way [5][22]. For instance, Saaty et al. [19] present an Analytical Hierarchy Process (AHP) to solve the SPM tool selection problem based on multiple criteria. AHP is a primary tool for solving multi-criteria decision-making problems, that organizes the critical aspects of the problem hierarchically. However, AHP does not regard the dependencies among different elements or alternatives [1]. To solve the stated limitation of AHP, researchers propose an Analytical Network Process (ANP), which is an extension of the AHP. The ANP attains better results in terms of accuracy compared to other strategies, including AHP, regarding the inter-dependencies and feedback in decision-making [23]. Due to the inherent features of the ANP, we present a decision-making framework for SPM tool selection based on ANP. In short, we make the following major contributions to the existing literature:

- We design a decision-making framework based on ANP for MCDM problems to help software project managers in choosing the most suitable SPM tool among a pool of available options.
- We put forward a practical step-by-step example to show how the proposed framework can be used for solving real-world complex MCDM problems in the context of software projects.

The remaining paper is organized in the following ordered sections; Section II puts forward a comprehensive review of state-of-the-art related to SPM tool selection. Section III presents problem formulation. In section IV, we present our proposed decision-making framework based on the ANP. Furthermore, Section V offers a practical example to illustrate the effectiveness of the proposed framework. Finally, Section VI draws the conclusion.

2 RELATED WORK

As mentioned earlier, existing literature discusses a plethora of SPM tools designed to help project managers in ensuring the successful completion of their projects within their time and budget constraints. Due to the abundance of these tools and the difference in their features, it is very hard to get a comprehensive list of the available tools [20][11]. For instance, some of the SPM tools are designed to help project managers during the whole life-cycle of the software projects while others can only be used during specific stages of the SPM. Due to the said reasons, the project managers find it very tedious to find and select the most suitable SPM tool based on the available features set [3].

In literature, the problem of selecting the most suitable tool for managing software projects is referred to as Multi-Criteria Decision-Making (MCDM) problem. MCDM is a set of concepts, procedures, and techniques used to make complex SPM tool selection decisions based on multiple criteria in a structured, well-organized and systematic way [22] [4]. For instance, Saaty et al. [19] present an Analytical Hierarchy Process (AHP) to solve the SPM tool selection problem based on multiple criteria. AHP is a primal and easy-to-use tool for solving multi-criteria decision-making problems which organizes the critical aspects of the problem hierarchically. However, AHP is not suitable for solving many real-world problems as it does not regard the complex dependencies among different elements or alternatives [1]. To solve the stated limitation of AHP, researchers propose an Analytical Network Process (ANP) which is an extension of the AHP. The ANP attains better results in terms of accuracy compared to other strategies including AHP regarding the inter-dependencies and feedback in decision-making [23]. The ANP achieves this by following the divide-and-conquer rule where it divides problems into smaller less complex subproblems that are significantly easy to handle [5].

Although a significant number of studies have been conducted on PM tool selection in different fields such as construction [9], wind energy investment [8] and risk management [6]. However, the techniques presented in these studies cannot be used effectively for software projects due to the complex nature of software projects compared to other projects. Very few studies have been done to solve MCDM problem in selecting the SPM tool. For instance, Ahmad et al. [1] proposed AHP in 2006. Kutlu et al. [12] used 12 evaluation criteria for SPM tool selection. The selection criteria were specified by the experts of the three well-known SPM tools such as the Microsoft Project, HPPPM, and Primavera. Project managers from different organizations analyzed the evaluation criteria. However, the AHP has the following two limitations: firstly, AHP appears to be time-consuming as it re-evaluates the alternatives if the evaluation criteria change [10]. Secondly, it cannot handle most real-world complex problems where we have inter-dependencies among the elements/alternatives.

Similarly, Rivas et al. [17] propose an SPM tool selection model using 11 evaluation criteria and 94 matrices. Moreover, the proposed framework formulates the requirements using GQM (goal-question-metric) and finally, experts evaluate the results obtained. Eastham et al. [7] presents a model to select a product lifecycle management (PLM) software by utilizing the SPM knowledge areas. The proposed framework comprises the following steps: (1) software search, (2) categorization based on the size of the company/firm, (3) a decision-maker regarding the importance of knowledge areas with respect to the features of the tool, and (4) evaluation of the decision in the previous step considering the available infrastructure/resources and cost.

Although several frameworks have been designed for MCDM problems, the SPM tool selection problem seems to be an understudied topic. This paper tries to fill this gap and offers an ANP-based

Table 1: The Saaty rating scale

Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the project.
3	Moderate importance	Experience, and judgment slightly favour one over the other.
5	Strong importance	Experience, and judgment strongly favour one over the other.
7	Very strong importance	Experience, and preference strongly favour one choice over the other. Its significance is proved by application.
9	Extreme importance	The evidence favouring one side over the other has the highest level of validity.
2,4,6,8	Intermediate values	When a compromise is essential.

framework for SPM tool selection. The idea is to select the most suitable SPM tool while considering the internal and external dependencies among different elements and the feedback among the decision elements and alternatives. The proposed approach, unlike existing frameworks, regards the demands of the software projects, the tool feature set, the relationship among the demands and feature set, and the interaction among different features of a tool.

3 PROBLEM FORMULATION

The SPM tool selection problem is an MCDM problem in which project managers have to choose the best tool for their software projects. The MCDM problem refers to the evaluation of a finite set of alternative choices over multiple decision criteria. In the SPM tool selection problem, the set of alternative choices contains different SPM tools. Moreover, the organizational needs define the decision and evaluation criteria for the SPM tool selection. Hence, in the SPM tool selection problem, the set of SPM tools is prioritized based on organizational needs.

Let $Alt = Alt_i$ and $C = C_j$ be the sets containing SPM tools as alternative choices and the organization requirements (needs) as decision/evaluation criteria, where $i \in \{1, 2, 3, \ldots, N\}$ and $j \in \{1, 2, 3, \ldots, M\}$. The problem now is to find the best alternative option (SPM tool), which is denoted by Alt_* over C_j. Let A represent a decision matrix of size $(M \times N)$, and $a_{ij} \in A$ represent the importance of each alternative choice in A in relation to each decision criterion C_j.

Each decision criterion will be assigned weights of importance (denoted by W_j for $j \in \{1, 2, 3, ..., N\}$). At this time, decision elements are compared pairwise in terms of their importance for their control criterion. We used a scale proposed by Saaty [18], as shown in Table 1, to determine the relative importance of all decision criteria [21] [16]. According to this scale, each criterion in terms of some criterion can have a value from the set: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9}.

4 PROPOSED DECISION FRAMEWORK

As mentioned earlier, the proposed decision framework for SPM tool selection is based on the ANP model, where we perform a pairwise comparison to calculate the importance of different factors based on certain criteria [19]. ANP supports both qualitative as well as quantitative approaches to solving the MCDM problems. The APN model has the following 4 steps:

(1) Problem identification: The first and foremost step is to identify and define the MCDM problem without any ambiguities. For instance, the problem statement will be written as "Selection of suitable SPM tool" if the software project manager tends to choose a suitable SPM tool for his ongoing projects based on certain requirements to be met.
(2) Pairwise comparisons and priority vectors: After defining the MCDM problem, the next step is to create a hierarchical structure of the problem using a top-to-bottom approach. Next, we need to organize and structure the objectives from broad to intermediate to the lowest level. Intermediate levels are the criterion upon which the subsequent element is based, and the lowest level is often a list of alternatives. Similar to AHP, the disjoint sets of criteria are compared based on their significance value. In addition, a pairwise comparison is performed within the sets/clusters to examine the intra-set dependencies. These dependencies are represented using an eigenvector to record the influence of one element on the other.
(3) A pairwise comparison matrix is produced as a result of comparing the components in the lower level with the elements in the level directly above it. It is possible to obtain a supermatrix by inserting the local priority vector into the columns that are appropriate for it. The super Matrix is a type of partition matrix, and each matrix segment in this matrix links two different clusters of a system.
(4) Taking into account the criteria as well as the priorities of the choices, we will now choose the finest ones: The normalised super Matrix is made up of the priority weights that are assigned to each of the criteria and the alternatives.

Based on the ANP model as described above, we design our proposed SPM tool selection framework as depicted in Figure 1. The proposed framework comprises seven main steps, and the details of each step as explained in the following text.

Step 1: In the first step of the proposed framework, we need to define the MCDM problem with specific goals. For instance, in the context of this paper, the "selection of suitable SPM tool" is the problem. Also, other necessary information such as organizational needs is collected.

Step 2: In this step, we establish the SPM tool selection criteria. However, the selection criteria may change with the software project requirements; therefore, the selection criteria can be defined loosely and should be open for future modifications. Moreover, we consider the evaluation factors identified by Mishra et al. [15]. There are 18 factors in total. However, it is not mandatory to use the same selection criteria; organizations may add or remove factors based on their requirements.

In our proposed framework, we define and classify decision criteria into the following three disjoint sets of criteria: (1) functionality

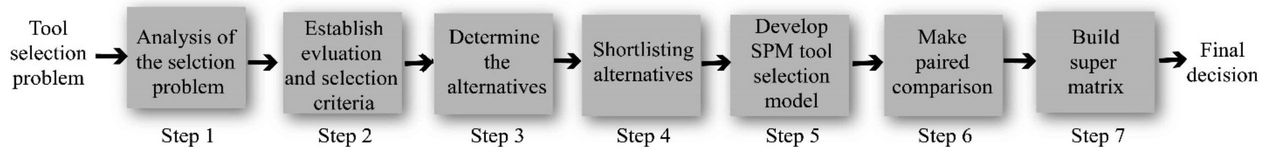

Figure 1: Proposed Framework

features (FF), (2) technical features (TF), and (3) vendor factors (VF). For instance, the FF criteria set contains criteria such as task allocation, resource management, estimation, file attachment, email facility, and collaboration. Similarly, the TF set comprises criteria such as user manual and online help. Finally, VF set consists of criteria such as popularity and service support. The whole list of criteria is depicted in Table 2.

Step 3: In this step, a list of all alternative SPM tools is created.

Step 4: In order to avoid a long list of alternative tools, a preselection of the alternative SPM tools is made. The list is then reviewed to ensure only those tools are included that are used the most and also meet the defined criteria.

Step 5: In this step of the proposed framework, the project team creates an inter and intra-dependency in the form of a network among the elements of the criteria sets defined in the previous step.

Step 6: After defining the dependency network, expert services are utilized to shortlist the alternative SPM tools by doing a pairwise comparison. During this process, each criterion is assigned a value by each expert according to a predefined scale. For instance, criterion 'A' is three times more significant than criteria 'D'. Finally, a normalized matrix is created based on the experts' assigned values by utilizing the following formula:

$$\boldsymbol{\beta}_{ij} = \frac{\alpha_{ij}}{\delta_j} \tag{1}$$

Where

$$\delta_j = \sum_{i=1}^{n} \alpha_{ij} \tag{2}$$

Step 7: Based on the dependency network developed in step 5, a supermatrix is obtained in step 7. Also, a priority vector is obtained from the pairwise comparison by signifying the impact of a certain set of criteria. The priority vector w_i is depicted by the following formula:

$$w_i = \frac{1}{n}\left[\sum_{i=1}^{j} \beta_{ij}\right] \tag{3}$$

Lastly, in this step, the consistency of the pairwise comparisons is checked and analyzed. The consistency index of the matrix is used for this purpose and is depicted as:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{4}$$

Where

$$\lambda_{\max} = \frac{1}{n}\left[\sum_{\mathrm{i=1}}^{\mathrm{n}} \frac{(\mathrm{A_W})_1}{\mathrm{w_1}}\right] \tag{5}$$

Table 2: Training performance of the three SAEs

Cluster	Name	Symbol
Functionality features	Task Scheduling	TS
	Resource Management	RM
	Collaboration	C
	Time Tracking	TT
	Estimating	E
	Risk Management	RM
	Change Management	CM
	File Attachment	FA
	Email Facility	EF
	Portfolio Management	PM
Technical features	Usability	Us
	Reliability	R
	System Architecture	SA
	User Manual	UM
	Online Help	OH
Vendor factors	Total Cost	TC
	Service Support	SS
	Popularity	P

Furthermore, a pairwise algorithm is utilized to obtain the weights for each set of criteria by multiplying them by their corresponding elements in the supermatrix. The sum of each column in the weighted supermatrix should be equal to one.

Finally, the limit supermatrix is computed by multiplying itself until each column of the limit supermatrix has the same value, as determined by the convergence of the Supermatrix row values. Through this activity, each element has a limited priority or impact on the other over the long term. By normalising and restricting the Super Matrix, a priority scale is generated upon completion of this process. The most effective tool will be the one with the highest priority. The general formula for computing the limit supermatrix is:

$$\frac{1}{n}\sum_{i=1}^{n} W^i = G \tag{6}$$

4.1 A Practical Example

The following example practically demonstrates how each step in the proposed framework (listed in Section 4) is performed to solve

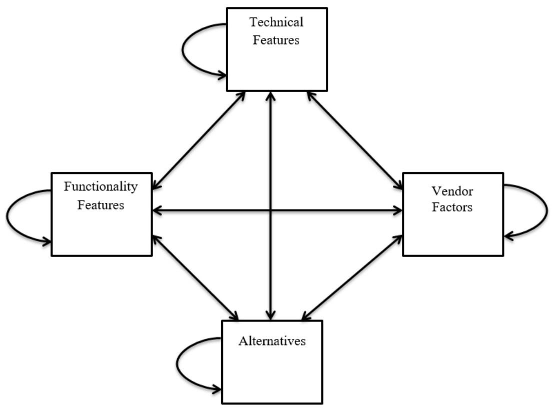

Figure 2: ANP Model

MCDM problems - we consider the SPM tool selection problem as an example.

Step 1: In this step, a broader and general set of SPM tool selection criteria is identified and analyzed. It is very important to perform this step very carefully as the outcome of subsequent steps depends on the selection criteria defined in this step.

Step 2: The set of SPM tool selection criteria is divided into 3 subsets/clusters; Table 2 depicts the elements of each set with a description.

Step 3: After defining the selection criteria and dividing them into cohesive clusters, the next step is to find SPM tools for alternative options to choose from.

Step 4: There are a plethora of SPM tools available in the marketplace to choose from. However, for simplicity, we choose only three of the most widely used tools available as alternatives in our example; namely they are Openproject (OP), Redmine (RM) and Microsoft Project (MP), [15].

Step 5: On the basis of the dependent Matrix depicted in Table 3, an ANP interaction network for selecting appropriate tools is constructed as shown in Figure 2.

Step 6: The Super Decision software is used to do a comparison of every criterion and option with regard to any selected criteria. Because of the constraints of space, the procedure will only be broken down for one criterion, namely Portfolio Management (PM). When it comes to portfolio management, Task Scheduling (TS) and Collaboration (C) are compared based on Portfolio Management (PM).

Suppose one of the experts says that TS is five times more important than C, as shown in Table 4. This information is used to compute the parameter δ_j that is used to compute normalized matrix as shown in Table 5 with respect to the equation (2).

Table 4: Parameters

PM	TS	**C**
TS	1	5
C	0.2	1
δ_j	1.2	6

Table 5: Normalised Matrix

PM	**TS**	**C**
TS	0.834	0.834
C	0.167	0.167

Now the vector of priorities can be calculated by using the formulation (3). The results are given below (Table 6)

Table 6: Priority Vectors

PM	w_i
TS	0.834
C	0.167

Following this, the various options are evaluated based on each of the criteria, and a consistency index is calculated. In this particular illustration, we look at each criterion in relation to the feature "Portfolio Management" as shown in Table 7. The formulation reference equation (3) is used to calculate the consistency index.

As PM depends upon SA in the technical feature cluster, it must be compared (Table 8)

As illustrated in Table 15, an unweighted Supermatrix is generated based on the priority vectors obtained in step 6. In this particular example, the values that were computed can be found in the 10^{th} column, which is labelled PM. Because each of the clusters in our example is dependent on the others, it is necessary to compare all of the clusters with one another (Table 9 - Table 12).

The priority values are used to obtain the dimension matrix, as shown in Table13.

In order to obtain the Weighted Supermatrix, the values of the dimension matrix are multiplied by the values of each of the relevant clusters, as shown in Table 16.

Finally, the limit Supermatrix is calculated using the formula (4). The limit matrix, as shown in Table 17, yields a limit priority of the influence of each element on every other element. Hence, this Matrix shows the relative priorities of each alternative as shown in Table 14.

5 DISCUSSION

Software SPM tools are essential for project managers to manage their ongoing software projects efficiently and effectively. However, selecting an appropriate SPM tool based on organizational requirements and the nature of software projects is a multiple-criteria decision-making (MCDM) problem and needs careful attention. The quality and success of software projects depend on how they are being managed, and finding the most suitable SPM tool among the available alternatives is a very challenging task for project managers.

Moreover, project managers may ignore the importance of the fact that SPM tools that fit some types of software projects may not work well for others. They may consider a subset of selection criteria that may not be good enough to filter from available tools

Table 3: Dependence Matrix

	TS	RM	C	TT	E	R	CM	FA	EF	PM	Us	RL	SA	UM	OH	TC	SS	P	OP	RM	MP
TS	0	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1
RM	1	0	1	1	1	0	1	0	0	0	0	0	0	1	0	0	0	1	1	1	1
C	1	1	0	1	1	1	1	1	1	1	1	0	0	1	1	0	1	1	1	1	1
TT	1	1	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	1	1	1
E	1	1	0	1	0	0	1	0	0	0	0	0	0	0	1	1	0	1	1	1	1
R	0	1	0	0	1	0	1	0	0	0	0	0	1	0	0	1	1	0	1	1	1
CM	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
FA	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1
EF	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	1	1
PM	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1
Us	0	0	1	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	1	1	1
RL	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	1	1	1
SA	0	0	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	1	1	1
UM	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1
OH	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	1
TC	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	1	1	1
SS	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	1	1
P	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	1	1	1
OP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
RM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
MP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0

Table 7: Comparing alternatives with respect to PM

PM	OP	RM	MP	w_i
OP	1	5	7	0.6580
RM	0.2	1	3	0.2627
MP	0.143	0.334	1	0.0780
		CI		0.003

Table 8: Comparing PM in Vendor Factors Cluster

PM	SA	w_i
SA	1	1
	CI	0.00

Table 9: Comparing Clusters with respect to Alternatives.

Alt	FF	TF	VF	Alt	Priority
FF	1.000	2.000	3.000	4.000	0.473
TF		1.000	1.000	3.000	0.236
VF			1.000	2.000	0.192
Alt				1.000	0.097
		CI			0.015

and choose the best one. Therefore, most project managers are biased in choosing an SPM tool based on their judgment or intuition.

The research community proposes systematic and formal selection strategies for MCDM problems to avoid the stated issue. In the broader context of MCDM problems, the literature studies the Analytic Hierarchy Process (AHP) technique to choose an appropriate option among multiple available alternatives. Although AHP is a simple and easy-to-use technique, it is ineffective in handling complex MCDM problems as it does not regard the hierarchical relationship among different factors. In this context, researchers propose the Analytic Network Process (ANP) technique to manage the inter-dependencies of other elements.

Table 10: Comparing Clusters with respect to Vender factors.

VF	FF	TF	VF	Alts	Priority
FF	1.000	0.333	1.000	2.000	0.289
TF		1.000	2.000	1.500	0.370
VF			1.000	3.000	0.226
Alt				1.000	0.116
		CI			0.207

Table 11: Comparing Clusters with respect to Functionality features.

FF	FF	TF	VF	Alt	Priority
FF	1.000	2.000	.0200	4.000	0.192
TF		1.000	1.000	3.000	0.299
VF			1.000	2.000	0.227
Alt				1.000	0.280
		CI			0.441

Table 12: Comparing Clusters with respect to Technical features

TF	FF	TF	VF	Alt	Priority
FF	1.000	5.000	0.250	3.000	0.336
TF		1.000	3.000	6.000	0.282
VF			1.000	4.000	0.293
Alt				1.000	0.087
		CI			0.802

Table 13: Dimension Matrix.

	FF	TF	VF	Alt
FF	0.192	0.336	0.289	0.473
TF	0.299	0.087	0.370	0.236
VF	0.227	0.082	0.226	0.191
Alt	0.280	0.293	0.116	0.096

Table 14: Synthesis for Alternatives.

Alternatives	Priorities	Rank
OP	0.0670	3
RM	0.1039	1
MP	0.0845	2

The proposed framework defines 18 evaluation criteria and classifies them into three disjoint sets. The proposed approach systematically creates inter-dependencies among the selection criteria and uses this information to select the most appropriate tool. The proposed framework allows project managers to evaluate and choose the best tool based on factors such as organizational needs and ongoing software projects. Moreover, the selection criteria in the proposed framework are designed to be flexible as the requirements for any software project may significantly change during its lifecycle.

6 CONCLUSIONS

In conclusion, the proposed SPM tool selection framework based on the ANP model can effectively and efficiently handle complex scenarios as it regards both qualitative and quantitative measures during the evaluation of SPM tools. The proposed framework defines 18 evaluation criteria and systematically creates inter-dependencies among them to select the most appropriate tool. Moreover, the proposed framework allows project managers to evaluate and choose the best tool based on factors such as organizational needs, and the selection criteria are designed to be flexible to adapt to changing requirements during the software project lifecycle.

However, the proposed framework has some limitations, such as the need for expert decision-makers to assign weights to selected evaluation criteria and the unclear nature of MCDM problems. To address these limitations, future research can introduce a fuzzy ANP (FANP) based framework. Overall, the proposed framework provides a practical solution to the challenging problem of SPM tool selection in the software industry.

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Table 15: Unweighted SuperMatrix.

	TS	RM	C	TT	E	R	CM	FA	EF	PM	US	RL	SA	UM	OH	TC	SS	P	OP	RM	MP
TS	0.0000	0.0572	0.0687	0.1196	0.0786	0.0110	0.0000	0.0000	0.0000	0.1604	0.0000	0.3363	0.0000	0.0000	0.0000	0.0000	0.0000	0.0540	0.0548	0.0544	0.0485
RM	0.5504	0.0000	0.6410	0.4520	0.7740	0.0000	0.5750	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4802	0.0000	0.0000	0.0000	0.1351	0.3791	0.7540	0.2457
C	0.2106	0.6513	0.0000	0.1763	0.1610	0.2888	0.6817	0.1686	0.1605	0.3210	0.3363	0.0000	0.0000	0.2882	0.5440	0.0000	0.2312	0.0000	0.4304	0.4696	0.4585
TT	0.3727	0.4593	0.1957	0.0000	0.0000	0.0000	0.7820	0.2400	0.0000	0.0000	0.0000	0.3363	0.0000	0.0000	0.0000	0.1699	0.0000	0.6311	0.6040	0.4895	0.1726
E	0.4650	0.5788	0.0000	0.1015	0.0000	0.0000	0.5250	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1584	0.0000	0.3650	0.4569	0.2756	0.1770
R	0.0000	0.7804	0.0000	0.0000	0.2020	0.0000	0.6618	0.0000	0.0000	0.0000	0.0000	0.0000	0.3363	0.0000	0.0000	0.6990	0.5780	0.0000	0.5260	0.7810	0.4634
CM	0.3272	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2190	0.3790	0.5171
FA	0.0000	0.0000	0.1299	0.0000	0.0000	0.0000	0.0000	0.0000	0.3210	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3971	0.6618	0.7107
EF	0.0000	0.0000	0.1562	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2449	0.0000	0.0000	0.0000	0.6350	0.4080	0.7398
PM	0.0000	0.1927	0.1160	0.0000	0.0000	0.3099	0.0000	0.0000	0.0000	0.1927	0.3363	0.0000	0.0000	0.0000	0.0000	0.4365	0.0000	0.0000	0.0512	0.6808	0.7649
US	0.0000	0.0000	0.1232	0.0000	0.0000	0.0000	0.0000	0.0000	0.1213	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1084	0.6090	0.4120
RL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1440	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3705	0.0000	0.6260	0.3148	0.2720
SA	0.0000	0.0000	0.9080	0.0000	0.0000	0.0000	0.0000	0.0000	0.3413	0.0000	0.0000	0.8700	0.8700	0.0000	0.0000	0.0000	0.0000	0.0000	0.4190	0.5400	0.7131
UM	0.0000	0.0000	0.3356	0.0000	0.0000	0.0000	0.2997	0.2997	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1613	0.5500	0.6141
OH	0.0000	0.0000	0.5191	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6780	0.8380	0.3303
TC	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2828	0.2828	0.0000	0.0000	0.0000	0.0000	0.8412	0.4840	0.1131
SS	0.0000	0.0000	0.1894	0.0000	0.0000	0.0000	0.0000	0.0000	0.2274	0.0000	0.0000	0.0000	0.0000	0.0000	0.9417	0.0000	0.0000	0.0000	0.7258	0.8800	0.5859
P	0.0000	0.0000	0.3770	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1885	0.2266	0.2266	0.0000	0.3214	0.5340	0.3040
OP	0.1098	0.0804	0.1096	0.1741	0.1741	0.1741	0.8040	0.1539	0.1539	0.1842	0.1932	0.2171	0.1715	0.1672	0.1612	0.6920	0.6010	0.6390	0.0000	0.4801	0.7202
RM	0.8602	0.8362	0.7797	0.3657	0.6676	0.7830	0.8362	0.1030	0.1030	0.3750	0.7713	0.4889	0.8903	0.9778	0.6160	0.3586	0.4169	0.2439	0.1200	0.0000	0.2400
MP	0.8410	0.1159	0.9353	0.6914	0.3822	0.2615	0.1159	0.2299	0.2299	0.2184	0.2290	0.2754	0.3303	0.2840	0.7040	0.1114	0.2823	0.2793	0.8402	0.4801	0.0000

Table 16: Weighted SuperMatrix.

	TS	RM	C	TT	E	R	CM	FA	EF	PM	US	RL	SA	UM	OH	TC	SS	P	OP	RM	MP
TS	0.0000	0.2969	0.3567	0.6207	0.4081	0.0572	0.0000	0.0000	0.0000	0.8333	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1871	0.1158	0.1149	0.1024
RM	0.2856	0.0000	0.3329	0.2349	0.4021	0.9882	0.2985	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1428	0.0000	0.0000	0.0000	0.4677	0.0801	0.1574	0.0519
C	0.1093	0.3381	0.0000	0.0915	0.0835	0.1498	0.3538	0.8751	0.8331	0.1666	1.0000	0.0000	0.0000	0.8571	0.1621	0.0000	0.8011	0.0000	0.9092	0.0992	0.0968
TT	0.1934	0.0238	0.1016	0.0000	0.0000	0.0000	0.0406	0.1251	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0588	0.0000	0.2183	0.1276	0.1034	0.0364
E	0.2417	0.3004	0.0000	0.0527	0.0000	0.0000	0.2726	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1088	0.5484	0.0000	0.1264	0.0965	0.0583	0.0074
R	0.0000	0.0405	0.0000	0.0000	0.1057	0.0343	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.2423	0.2011	0.0000	0.1113	0.0165	0.0975
CM	0.1698	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0464	0.0801	0.1092
FA	0.0000	0.0000	0.0674	0.0000	0.0000	0.0000	0.0000	0.0000	0.1667	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0839	0.1398	0.1501
EF	0.0000	0.0000	0.0810	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7285	0.0000	0.0000	0.0000	0.1343	0.0863	0.1562
PM	0.0000	1.0000	0.0602	0.0000	0.0000	0.1608	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1505	0.0000	0.0000	0.1083	0.1438	0.1615
US	0.0000	0.0000	0.4111	0.0000	0.0000	0.0000	0.0000	0.0000	0.4050	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4595	0.2584	0.1749
RL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4806	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.2655	0.1334	0.1115
SA	0.0000	0.0000	0.3031	0.0000	0.0000	0.0000	0.0000	0.0000	0.1139	0.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1777	0.2291	0.3101
UM	0.0000	0.0000	0.1121	0.0000	0.0000	0.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0683	0.0236	0.2602
OH	0.0000	0.0000	0.1732	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0287	0.3552	0.1399
TC	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.4430	0.2551	0.5956
SS	0.0000	0.0000	0.8331	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3330	0.0000	0.0000	0.0000	0.3873	0.4636	0.3084
P	0.0000	0.0000	0.1661	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6660	1.0000	1.0000	0.0000	0.1692	0.2811	0.0955
OP	0.3922	0.2871	0.3941	0.6221	0.6251	0.6256	0.2871	0.5498	0.5498	0.6589	0.6589	0.7359	0.5842	0.5695	0.5495	0.5951	0.5171	0.5499	0.0000	0.5001	0.7501
RM	0.3071	0.2986	0.2784	0.1306	0.2384	0.2796	0.2986	0.3681	0.3681	0.2627	0.2627	0.1665	0.3032	0.3334	0.2098	0.3084	0.3585	0.2098	0.1251	0.0000	0.2501
MP	0.3005	0.4141	0.3341	0.2469	0.1365	0.0936	0.4141	0.0821	0.0821	0.0781	0.0781	0.0938	0.1125	0.0971	0.2401	0.0958	0.1243	0.2401	0.8751	0.5001	0.0000

Table 17: Limit SuperMatrix.

	TS	RM	C	TT	E	R	CM	FA	EF	PM	US	RL	SA	UM	OH	TC	SS	P	OP	RM	MP
TS	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108	0.0108
RM	0.0564	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563	0.0563
C	0.0637	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638
TT	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472	0.0472
E	0.0325	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326	0.0326
R	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664	0.0664
CM	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226	0.0226
FA	0.0393	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392
EF	0.0375	0.0374	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375	0.0375
PM	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467	0.0467
US	0.0263	0.0262	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263	0.0263
RL	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276	0.0276
SA	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661	0.0661
UM	0.0357	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356	0.0356
OH	0.0433	0.0431	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432	0.0432
TC	0.0324	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323	0.0323
SS	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559	0.0559
P	0.0346	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345	0.0345
OP	0.0669	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670	0.0670
RM	0.1037	0.1041	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039	0.1039
MP	0.0844	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845	0.0845