ISSN No:-2456-2165

A Survey on Multi-Criteria Decision Making Methods in Software Engineering

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Abstract:- Multi-criteria decision making methods have been widely used in different fields of development system to attain significant results. These are the quantitative methods used for reducing the complexity of system design and to arrive at final statement considering the involvement of the number of stakeholders to make a decision. With the increased alternatives and the constraints decision making becomes complex issue. Many researchers have proposed several techniques to enhance software quality by adopting multi-criteria decision making methods in the area such as Testing Criteria for UML Models, Software Project Selection, Risk Analysis, Quality Evaluation, and Assessment etc. This paper mainly focuses on combining all the work related to the implementation of MCDM in software engineering, for making a decision in the different area of application. This highlights more prominently used methods and the advancements in those methods in the recent years.

***Keywords**:- Multi criteria decision making (MCDM), Decision Making (DM), Software Engineering (SE), Prioritizing, Alternatives, Constraints.*

I. INTRODUCTION

Decision making (DM) always aims for deciding on the optimal solution for a problem. It depends on the decision maker to study the possibilities and to select from multiple options to attain the desired outcome [1]. This could be statistical analysis, quantitative analysis or survey to attain the solution satisfying requirements and reducing the probable conflict on problem definition. MCDM majorly focuses on decision making to attain the ideal result when multiple preferences are provided. Prioritization is also one of the factors which have to be considered with the increase of alternatives. The complexity of the system also increases as stakeholder involves actively in the system design. MCDM mainly classified as Multi-attribute decision making (MADM) and Multi-objective decision making (MODM). MADM helps in selection of alternatives from a given set [2].These alternatives can be evaluated depending on the preferences. In economics, utility theory is adopted to study the preference of DM and in multi-attribute systems, multiple attribute utility theory (MAUT) is used for preference analysis. The utility adaptive (UTA) method uses MAUT along with regression and linear programming to analyse the DM preferences. MAUT works with the principle of independence of attributes and UAT works with an independence of variables [3]. MODM is used for obtaining continuous set of solutions when two or more criteria are present. Majorly MCDM deals with distinct alternatives, defined by constraint at different intervals. Constraint values are retrieved either manually or by mathematical evaluation. Information retrieved could be actual or fuzzy, depending on the intervals. A modern MCDM method provides the platform for the decision maker to retrieve these data. One of the main stages of MCDM is deciding on the aggregation method to finalize the decision. However recent advancement in MCDM has given a variety of evaluation theories and the assessment techniques. There are no definite methods adopted for decision making. Depending on the application and the object of comparison, aggregation method is chosen to decide on the priorities and to rank the alternatives [4].

II. REVIEW OF LITERATURE

The decision support methods have been implemented in the various applications satisfying the constraints to the major extent. These methods came into existence in early 1960 and the work continued with the different application. The complexity in decision making, increased with the number of alternatives and the stakeholder involvement resulting in the implementation of MCDM. Depending on the functional requirement different techniques can be used for the attainment of the solution using either linear programming or non-linear programming or discrete optimization technique. Abbas Mardani et.al [4] published study on the MCDM techniques and their applications in Energy, environmental and sustainability, Operation research and soft computing, Knowledge management etc. Vaidya, O. S. & Kumar, S [5] shows survey on AHP used in Energy management, E-commerce, Government sectors etc. Achimugu P.et.al [6] gives details on a literature review of Software Requirements Prioritization. Vicent Penades-Pla et.al [7] work details about a review of Multi-Criteria Decision-Making Methods Applied to the Sustainable Bridge Design. This study mainly highlights MCDM application in different areas of software engineering from 2001 to 2018. The sources referred are IEEE, Science Direct, Research Gate, Conferences and Journals. Some of the applications are tabulated in Table I. and are discussed as follows.

In this study total of fifty-seven papers which referred to software engineering application have been considered. It is observed that twenty papers discuss software application based on the implementation using the AHP method and twenty-four papers refer to fuzzy AHP method. AHP is considered to be the foundation method in decision making widely used in applications like optimized model selection, software selection, tool selection, qualitative evaluation, quality control systems and Project management evaluation etc. (A. Kengpol, C. O Brien [8],2001, Cagno et al.[9],2001; Badri [10],2001; Al-Harbi [11],2001).

ISSN No:-2456-2165

Table I. MCDM Techniques applied to different area of Software Engineering

Sl. No	MCDM Technique	Aspect	Authors	Year Published
1	AHP	Tool selection for advanced technology	A. Kengpol, C. O Brien [8]	2001
2	AHP	Simulation approach for quantitative evaluation	Cagno et al. [9]	2001
3	AHP	Model quality control systems	Badri [10]	2001
4	AHP	Project management evaluation	Al-Harbi [11]	2001
5	Fuzzy AHP	Program aspect Assessment	Belton and Stewart [12]	2002
6	AHP	Software selection	V.Lai et al. [13]	2002
7	AHP	Selection of appropriate project delivery method	Al Khalil [14]	2002
8	AHP	Structural approach for measuring functional dependency	J.C.Y.Su. et al. [15]	2003
9	Fuzzy logic and AHP	Software development strategy selection	Buyukozkan G.et al.[16]	2004
10	Fuzzy AHP	Ranking of the factors behind the success of E-commerce	Kong and Liu [17]	2005
11	Fuzzy AHP	Evaluation and assessment of project risks	Kahraman and Tuysuz [18]	2006
12	AHP	Model for selecting a software project management tool	Ahmad and Laplante [19]	2006
13	AHP	Reliability assessment method	Tamura and Yamada [202]	2006
14	Fuzzy MCDM	Evaluation of information technology projects	Thomaidis et al. [21]	2006
15	Modified TOPSIS and ANP	COTS evaluation	Shyur H.J [22]	2006
16	Fuzzy AHP and TOPSIS	Project selection	Mahmoodzadeh et al. [23]	2007
17	AHP and Simulator	Machine tool selection	Z. AYAG [24]	2007
18	AHP	Soft computing scheme and genetic Algorithms	Lin, Wang, & Yu [25]	2008
19	DEMATEL and ANP	Evaluation of knowledge management system	Wu [26]	2008
20	Fuzzy Vikor and Fuzzy Delphi	Measuring the performance of software development projects	Buyukozkan G.,Ruan D. [27]	2008
21	FAHP & FTOPSIS	Evaluating Software Trustworthiness	LiShi & Shalin Yang [28]	2009
22	Fuzzy AHP	Comparing an automated functional and regression testing tool	Srivastava and Ray [29]	2009
23	AHP	Selecting and evaluation of project	Palcic I and Lalic B [30]	2009
24	PROMETHEE and AHP with fuzzy logic	Framework for software selection	Rao R.V. and Rajesh T.S. [31]	2009
25	AHP	Software developers to improve software quality	Trienekens et al. [32]	2010
26	AHP	Framework to evaluate information security policy performance	Syamsuddin I. and Junseok H. [33]	2010
27	MCDM	Software defect detection algorithms selection	Peng Y et al. [34]	2010
28	Fuzzy AHP	Risk factors and E-commerce transaction	Wei et al.[35]	2011
29	Fuzzy AHP	Tool for selecting the quality parameters	Challa et al.[36]	2011
30	AHP	Assessment of the quality of ensemble methods in software defect prediction	Peng Y et al. [37]	2011
31	TOPSIS	Assessment of building requirement systems	Li, Lai, & Kao [38]	2011
32	Fuzzy AHP	Appropriate web development platform	Sarfaraj et al. [39]	2012
33	Fuzzy AHP	Software Project Selection	Bakshi et al.[40]	2012
34	Fuzzy AHP and Fuzzy TOPSIS	Software life cycle model	Mumin Hicdurmaz [41]	2012
35	AHP &FAHP	Comparison study on the selection of effort estimation model	Sumeet Kaur Sehra et al. [42]	2012
36	AHP	Evaluation of E-commerce security	Yajuan Zhang et al. [43]	2012
37	Fuzzy AHP	Assessing the quality of service delivery of websites	Vatanseverr and Akgul [44]	2014
38	Fuzzy AHP	Information security risk assessment	Lee [45]	2014
39	Fuzzy AHP	Ranking of risks	Askari et al. [46]	2014
40	AHP	Selection process of open source software (OSS) products	Jusoh et al.[47]	2014
41	Fuzzy AHP	Selection of software quality models	R.Kohli and S. K. Sehra [48]	2014
42	Fuzzy AHP	Selection of Computer aided manufacturing (CAM) software	Zeki Ayağ [49]	2014
43	Fuzzy AHP	Software development life cycle (SDLC)	Khan et al. [50]	2014

44	AHP and Fuzzy comprehensive method	Information Security Risk Analysis	Ming-Chang Lee [51]	2014
45	IGAPE,AHP and TOPSIS	Integrating and Prioritising goals	Vinay S et al. [52]	2014
46	AHP & Genetic Algorithm	Automating the Migration of Web Application Clusters to Public Clouds	Michael Menzel et al. [53]	2015
47	Fuzzy AHP	Software Quality model selection	Sumeet Kaur Sehra et al. [54]	2016
48	ELECTRE	Requirement Prioritization	S. A. Sahaaya Arul Mary and G. Suganya [55]	2016
49	SMARTER	Selection of Agile methodologies in Software development projects	Vanessa B.S.Silva et al. [56]	2016
50	TOPSIS and Fuzzy TOPSIS	Exploring the issues and limitations	Elissa Nadia Madi et.al [57]	2016
51	ANP	Requirements Prioritization	Javed Ali Khan et al. [58]	2016
52	Hybrid Cumulatie Voting and Macbeth	Hybrid model in Requirement Prioritization	Romulo Santos et al. [59]	2016
53	Data Analysis	Decision Support for Requirements Prioritization	Hadeel E. Elsherbeiny et al.[60]	2017
54	AHP	Gamification for prioritising requirements in Software engineering	Kifetew Meshesha Fitsum et al.[61]	2017
55	AHP	Review of Requirements Prioritization Techniques and Analysis	Raneem Qaddoura et al. [62]	2017
56	Fuzzy Weiger's Method	Rank Priorities in Requirement Engineering	Hassan, Abeer & Ramadan Nagy [63]	2017
57	Fuzzy logic	Hybrid Prioritization Technique for Software Requirements	Hassan, Abeer & Ramadan Nagy [64]	2018

Belton and Stewart [12] have evaluated programs qualitatively based on the different factors of software testability using FAHP, in their studies. Kong and Liu [17] have studied the ranking of the factors behind the success of E-commerce. They have considered different criteria and sub-criteria for the successful evaluation. The study concluded with the "Trust" as a major criteria and "Security" as the sub-criteria of Trust. Kahraman and Tuysuz [18] have suggested that the MCDM can be used for evaluation and assessment of project risks. A method for project selection is suggested by Mahmoodzadeh et al. [23] using fuzzy AHP and TOPSIS technique method for project selection. Srivastava and Ray [29] suggested FAHP for comparing an automated functional and regression testing tool. Wei et al.[35] implemented FAHP to Customer E-commerce transaction system's security risk level analysis. Challa et al.[36] have used FAHP to develop a tool for selecting quality parameters by considering developer, project manager, and user perspective. Sarfaraj et al.[39] have used Fuzzy AHP for identifying the appropriate web development platform. The proposed model took into account four criteria, namely security, compatibility, performance and licensing cost for choosing the best platform. Bakshi et al.[40] used FAHP for selection of software project. Vatansever and Akgul [44] proposed Fuzzy AHP for assessing the quality of service delivery of websites. The major importance was given to the quality concern and the vendor specific quality turned out to be most significant from the study. Lee [45] has used FAHP for information security risk assessment. Using FAHP Askari et al. [46] achieved Ranking of risks considering project objectives and alternatives.

Jusoh et al. [47] implemented AHP for the selection of Open Source Software (OSS) based on independent criteria defined by stakeholders. The selection practices change between the contributors to the organizations. Every operator has a subjective opinion on the selection of software depending on the problem to be solved. The factors included for study are quality of the system, Information and service delivered. The author included twelve measures for selection; like reliability, usability, performance efficiency, functionality, and competence etc. The features were defined by the system to satisfy the requirements of OSS. AHP was effectively applied to identify the best alternatives for selecting the OSS. Future work suggests the use of fuzzy theory for converting the requirements into a hierarchical structure representing the weights corresponding to the requirement. Group decision making can be used in future for including all the stakeholders for decision making. Vinay S el at. [52] proposed combining IGAPE along with AHP and TOPSIS. The results of Integration of Goals after Prioritization and evaluation were provided as input to decision making methods AHP and TOPSIS. This proposed model was used in requirement engineering to attain validation for various decisions when multiple stakeholders are involved. The major work included identifying strategies for decision support system and framework generation. The proposed method was explained with an e-commerce application. The suggested future work, to consider different stakeholders while prioritizing requirements or hard goals and exploring game theoretic approaches in the decision support system.

Sumeet Kaur Sehra et al. [54] highlighted some of the application of FAHP in their work of Software Quality model selection. The work shows the FAHP can be successfully implemented in solving software engineering problems like finding web development platform, assessing the quality of website and success factor evaluation of e-commerce. Study included three different criteria: reliability, efficiency, and maintainability to evaluate McCall, Boehm and ISO9126 software quality model. The selection of the model is done on the basis of normalized weights. The weights for criteria are calculated using both FAHP and AHP and the comparison is done. The weight factor of 1.39 in case of AHP shows Boehm's model selection and with FAHP normalized weight is 0.38 for ISO9126 resulting in the best software model. The results depend on the specific application and the decision maker's viewpoint during the value assignment. Since the decision making is uncertain, the FAHP method can be considered as one of the best solutions for ranking and for assessment issues in software engineering. Sahaaya et al. [55] implemented ELECTRE method for prioritizing the requirements. ELECTRE is one of the multi-criteria decision-making methods mainly used for ranking initiatives. In this proposed system, inputs from multiple stakeholders were taken using 100 points method and the ranking was done using ELECTRE. It is observed that the resulting system had the advantage of the cost of implementation and the man-hour requirement over conventional development system. The drawback of the system is with the 100 points method which is restricted when large numbers of requirements are considered. The authors suggest the use of fuzzy methods in future for taking the preferences of the stakeholders.

Vanessa B.S.Silva et al. [56] presented an multi-criteria method SMARTER (Simple Multi-Attribute Rating Technique Exploiting Ranks) for the selection of agile software development methodology for small and medium enterprises to match the requirement of software development. The selection was considered among the popular agile process models DSDM (Dynamic Systems Development Method), SCRUM, XP2 and Crystal. The alternatives are restricted to these methodologies. Set of criteria was defined and the survey was conducted. The resulting linguistic values were then converted into numerical indices to attain the final results. Ranking of the methodology was done based on the multi-attribute values. The procedure is easier and cost effective but results in lack of complete information for the robust selection of the process. This is one of the recent works with SMARTER application in the software engineering domain. Researcher has concluded the study with some of his observation for the further study. Future work suggested using numerical scaling may provide better result rather than survey methods for precise criteria. Efficient quantitative analysis of linguistic scales for the evaluation of the alternatives was suggested as future work. Elissa Nadia Madi et al. [57] discussed different stages involved in TOPSIS and FTOPSIS methods and highlights the key difference between these two methods. This work also details about the issues and the challenges of FTOPSIS method. Identifying these drawbacks, the solution has been suggested which can be used in future for improving the exciting fuzzy TOPSIS methods for providing more consistent decisions. Javed Ali Khan et al.[58] proposed model for prioritizing interdependent requirements using ANP. The researcher suggests that ANP is one of the best-suited methods for requirement prioritizing because of its consistent result which depends on proportion scale. The study shows that ANP provides better results in prioritizing than AHP. The simulation performed using MATLAB software. Future work proposes using ANP in the industry for requirement prioritizing during software development.

Romulo Santos et al. [59] makes use of Hybrid Cumulative Voting (HCV) prioritizing technique for analysing the requirements through the questionnaire method. Case study of Commercial Off-The-Shelf (COTS) software requirements prioritization was selected. Some of the potential software user's response was taken online and documented. The database is processed using HCV method to obtain weights using ratio scale. The resulted response was consolidated using Macbeth (Measuring Attractiveness by the Categorical Based Evaluation Technique) process. It is found that the method could satisfy the features of Market-driven software development. Future work suggests case study favouring global scope, with region's culture and economic weight as additional features. Another improvement suggested is to use Integer Linear programming with additional selection criteria as cost and the requirement interdependency. Hadeel E. Elsherbeiny et al.[60] used Statistical analysis to prioritize the requirements for a system involving a large number of stakeholders. The researcher used Rate P method of eliciting the requirements, as it has received a high rating from the respondents out of the three methods RateP, RankP, and PointP. In Rate P, the rating is provided from 0 to 5(lowest to highest) and -1 for the not required requirement. The data collection is done using a questionnaire, brainstorming and group discussions etc. The study is done over 76 stakeholders, 10 project objectives, 48 requirements and 104 specific requirements. The input to the system is non-prioritized requirements and the output is suggested prioritized requirements. Researcher uses SPSS for prioritizing and to get the correlation to predict the stakeholder's requirements.

Kifetew Meshesha Fitsum et al. [61] discuss Gamification concept adopted for requirements prioritization in software engineering. Decision-Making Game (DMGame) is a software tool designed for supporting requirement engineers. DMGame makes use of gamification and automated reasoning for requirement prioritization and to involve stakeholders to contribute to the decision making process. DMGame depends on Online Role-Playing Game (ORPG) enfolding manual prediction algorithms into a decision making. Process observed to be faster, considering individual stakeholders contribution and automating prioritizing activities. For automated reasoning, AHP algorithm is used for ranking alternatives using pairwise comparison. It is customized to handle multiple stakeholders. Future work suggests a Non-pairwise approach using multi-objective optimization as an alternative for AHP for a large number of requirements. Raneem Qaddoura et al. [62] presented a review of different methods used for requirements prioritization. The selection of the methods is done depending on the type of the project and the requirement to be satisfied. The comparison of these methods was done using many parameters, some of them are complexity, ease of use, the reliability of results, fault tolerance etc. Future work is to study more data mining and machine learning techniques and their comparisons with the exciting technique.

ISSN No:-2456-2165

Hassan Abeer & Ramadan Nagy [63] discussed different methods adopted for prioritizing the requirements for developing systems by different researchers. This paper proposes a framework which depends on the Fuzzy Wieger's Method for prioritizing requirements by assigning weight values to benefits, penalty, cost, and risk of individual requirement. The comparison is done with the classical Wieger's method with the numerical example using MATLAB and spreadsheet. Recent work shows Hassan Abeer & Ramadan Nagy [64] proposed a hybrid model for requirement prioritization using three different techniques such as QFD (Quality Function Deployment), CV (Cumulative Voting), and AHP (Analytical Hierarchy Process) using fuzzy technique. The idea of using Fuzzy approach is mainly due to the uncertainty in the decisions of stakeholders. Fuzzy version gives a closed look to the real world considering the vagueness in decision making. The degree of importance of requirements divided as large, medium and small for prioritization purpose. This method overcomes the problem of complicated decision making structures, collective decision making and to handle an ambiguity during group decision making. Author also compares the proposed fuzzy version of this method with the classical form, ensures the ease of implementation, the efficiency and effective management of uncertainty in decision making.

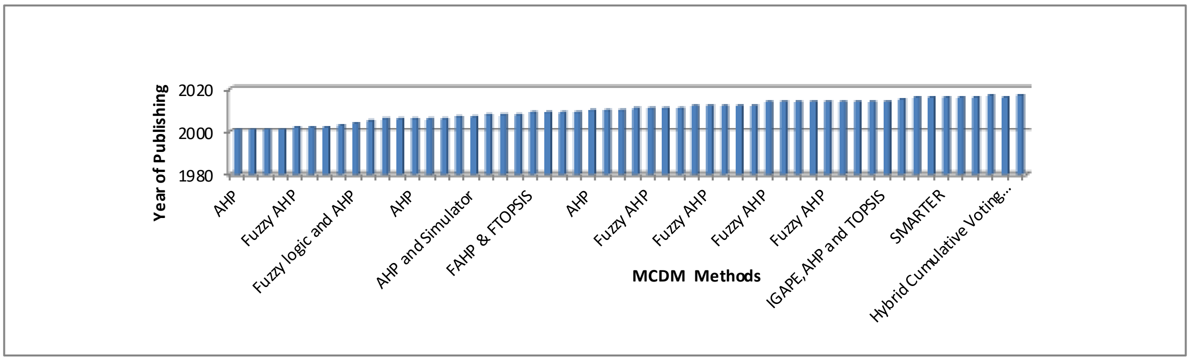

Figure 1: MCDM techniques in Software Engineering

The chart (Figure 1) shows various MCDM techniques used in different area of software engineering over the years. Some of the study shows combining different MCDM methods to increase efficiency and to attain consistent result. It is observed from the study that the AHP and FAHP are more prominently used methods.

III. MCDM METHODS

A. Analytical Hierarchical Process (AHP) was proposed by Thomas Saaty [65] in 1980, to decompose problem into a hierarchical structure and a pairwise comparison is performed over the alternatives to decide on the preferences. AHP finds wide applications in many fields of complex, real-world challenges comprising of number of alternatives. The difficulty in assigning the weights to the alternatives resulted in fuzzy logic implementation, resulting in fuzzy AHP method [66]. Instead of comparing two values fuzzy logic resulted in the intermediate values which made an evaluation of alternatives easier. Altogether AHP works on the theory of independent criteria.

B. Analytic Network Process (ANP) method [67] developed in 1996 allows the dependencies between the criteria. Most of the problems cannot be arranged in hierarchical form because of the contribution from different levels. ANP is represented by a network, with the cycles interconnected to the system. The major drawback of ANP is uncertainty in human judgment which results in a deficiency in the evaluation of important criteria. Fuzzy ANP derives local weights using fuzzy preference programming method. This local weight forms super matrix to obtain global weights for ranking the alternatives.

C. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) which was introduced by Hwang and Yoon in 1981[68] is used along with AHP to increase the efficiency in decision making. TOPSIS is based on aggregation and representing decision close to an ideal solution. The method uses vector normalization to calculate the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solutions. An initial work with Fuzzy TOPSIS method for group decision-making was implemented by Chen in 2000. In this work, decision makers use fuzzy sets to allot the semantic values to the alternatives [69].

D. VIKOR was originally developed by Serafim Opricovic in 1979 and an application was published in 1980 to solve decision problems with conflicting criteria's. The method is based on aggregation and decision representation close to an ideal solution as that in TOPSIS. In VIKOR linear normalization method is used [70]. It is a compromise ranking method providing maximum utility for the majority and the minimum utility with minor preferences for the individual.

E. Elimination and Choice Translating algorithm *(ELECTRE)* family includes ELECTRE I, II, III, IV, IS and TRI methods which appear similar but differ in the way decision problem is solved. The ELECTRE was introduced by Benayoun, Roy, and Sussman in 1968 [71]. The method was later developed by Bernard Roy (Roy, 1996).ELECTRE III is considered to be more efficient in ranking analysis. This method mainly depends on the evaluation of concordance index and discordance index.

Ascending and descending pre-order is done and then the alternative ranking is evaluated.

F. PROMETHEE [72] and its complement Geometric analysis for interactive aid (GAIA) developed in the early 1980s are majorly used to conquer alternate best solutions to attain goals rather providing a right decision. These methods help the developers in designing the framework for the process, analysing the solution and prioritizing the alternatives.

G. SMARTER (SMART Exploiting Ranks) method, based on MAUT (Multiple Attribute Utility Theory) which is mainly used for preference analysis. This method belongs to SMART (Simple Multi-Attribute Rating Technique) proposed by Edwards and Barron, a family of compensatory methods. SMARTER uses Rank of Order Centroid (ROC) [73] for elicitation of weights, which converts ranking criteria into numerical weights. SMARTER is divided into different steps; defining the goal and recognizing decision makers, Criteria setting, defining goal alternative, evaluating criteria and alternatives, analysis of prominent alternatives, calculating one-dimensional value function and finally weight swing and ROC method implementation.

H. Wieger's method with fuzzy logic is used for requirement prioritizing in the recent paper. The method depends on benefits, penalty, risk, and cost of each requirement. Weights are evaluated in terms of the membership function. Implementation is done using MATLAB for membership function and designer inference rules to determine the priority based on the fuzzy logic. It is considered to be more suitable for the real-time implementation, as the degree of importance of requirements is very high during the development stage. The progress in the MCDM methods shows that fuzzy version of the methods is more appropriate because of the vagueness in the decisions made by the stakeholders and the ambiguity in the requirement [64]. Most of the work shows that fuzzy concepts can better handle uncertainty during complex decision making.

IV. OBSERVATION AND CONCLUSION

Decision support methods are majorly used in many different areas such as energy system, business sectors, and software engineering etc. Recent trends shows decision-making methods have made researcher to innovate new methods to achieve more competent outcomes. The study highlights the application of multi-criteria decision-making methods in the different phases of software engineering life cycle. Recent survey shows most of the work with combination of available MCDM methods to improve on the efficiency of decision making. Overall work shows that the AHP and the Fuzzy AHP are more frequently used methods. This is mainly because of simplicity in understanding and ease of implementation, forming a strong base for decision-making methods. Recent work also shows the implementation of TOPSIS, SMARTER, ELECTRE, PROMETHEE and Fuzzy Wieger's Methods for different application in software engineering. Most of these traditional methods have limitations when used for solving real world problems. Thus, decision-making should take into account the complexity to deal with actual run time systems. Future work suggests a hybrid model of decision-making method, combining essential features from existing methods, to increase the efficiency and consistency of the software life cycle model.

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