Multi-Criteria Decision-Making Methods: A Case of Software Vendor Selection

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Abstract – **Various multi-criteria decision-making methods have been utilized in literature to address vendor selection challenges in various contexts. This study reflects on these decision-making techniques for vendor selection in the software ecosystem during software outsourcing. For the same, firstly, a requirement framework for the decision-making process for software vendor selection is proposed. Afterwards, five selected different multi-criteria decision-making techniques are compared and critically analysed against this requirement framework. This study supports software practitioners and decision-makers by providing information about which decision-making method to choose, considering the trade-off between the benefits and drawbacks of adopting each method or using hybrid approaches by combining two or more techniques with fuzzy logic. It is found that decision-making techniques generally lack in modelling the problem itself and handling the conflicts and uncertainties that may prevail during the decision-making process. Furthermore, it has been identified that artificial neural networks (ANN) and analytic network process (ANP) can support the dependencies between alternatives and criteria while handling complex interactions in the software ecosystem.**

On the other hand, due to its comparative ease of use, analytic hierarchy process (AHP) can serve better in scenarios where decision-makers are not experienced, or past data to train the ANN or ANP models is unavailable.

Keywords **– Software business development, decision-making, software ecosystem, vendor selection, vendor analysis.**

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1. Introduction

Software technology and related businesses are changing rapidly. Businesses and industries are exploring innovative business models to adapt to the swift technological advancements. The software ecosystem emerges as a direct outcome of these experiments conducted by various companies [1]. As highlighted in a study conducted by Schwarz [2], organisations are willing to invest in an outsourcing relationship because they perceive its value. Even though the software experts are interested in working in the software ecosystem, complex interactions among entities bring barriers to adopters [3]. One of the barriers organisations often face during decision-making is deciding on the appropriate software vendor/service provider.

Despite being recognised as crucial to the success of an outsourcing alliance, the decision-making process is still not fully comprehended [4], [5]. Selecting the most appropriate vendor for any company based on its structural and organisational goals can be highly cumbersome if done manually [6]. Manual methods are not only time-consuming but can also lead to a number of errors, which are not ideal for the decision-making process. Thus, using effective multi-criteria decision-making (MCDM) techniques can significantly simplify the process of selecting the most appropriate vendor in terms of both time taken and errors made.

Multiple studies exist which utilise different decision-making techniques in various settings to resolve vendor selection challenges prevalent in manual methods [7], [8], [9], [10].

However, to the best of our knowledge, none of these studies reflects on utilising MCDM techniques specifically for vendor selection in the software ecosystem for software outsourcing. This study takes a step forward and compares the most used MCDM techniques for vendor selection against the proposed requirement framework of the software ecosystem. Further, a few studies have performed one-versus-one comparisons of these techniques [11] in other contexts; still there is a research gap with respect to exploring and comparing MCDM techniques specifically for decision-making in software ecosystems. Considering this research gap, the following research question (RQ) has been set for this study.

RQ: To what extent do different MCDM techniques fit the vendor selection process in a software ecosystem?

To answer this research question, the present paper first investigates how different MCDM techniques are utilized by existing studies in decision-making scenarios for different settings. Thereafter, a requirement framework for the vendor selection process in the software ecosystem is proposed. Further, these MCDM techniques are compared and reflected against this requirement framework.

The structure of this research article is as follows. The next section discusses the related work and methodology. Section 3 details the requirement framework for vendor selection in the software ecosystem. The subsequent section details the various MCDMs used to select the best vendor in various contexts. Section 5 draws parallels and contrasts between the methods and critically analyses them with respect to the proposed requirement framework. Section 6 concludes the study. The last section provides the implications of the study along with future work.

2. Related Work and Methodology

Various studies reported the challenges prevalent in the software ecosystem from various perspectives. Kasse *et al.* [12] interpreted that the main challenge for businesses wanting to work with vendors is the vendors' lack of maturity or differences in maturity levels between the vendor and the client. According to Imtiaz *et al.* [13], task allocation is the main obstacle for outsourcing projects. Similarly, Ulziit *et al.* [14] enumerated three principal challenges in software maintenance within distributed software development: communication, control, and coordination. Additionally, Akbar *et al.* [15] recognized difficulties in managing requirement chains in distributed development scenarios.

Rani *et al.* [16] presented the challenges associated with outsourcing from the perspective of the company which is outsourcing. Hiring appropriate vendors for given requirements has been reported to be the most crucial challenge in the software ecosystem.

Clark Jr *et al.* [17], Niu *et al*. [18], and Turban [19] have developed decision support systems (DSS) to assist decision-makers across various decision-making stages. Decision analysis techniques presented by Stankevich [20], and Zavadskas and Turskis [21] and model-based DSS proposed by Niu *et al*. [18] and Turban *et al.* [19] are structured methods employed to construct decision models and optimize diverse selection variables [22], [23]. These decision support systems are based on different multi-criteria decision-making (MCDM) methods. However, there is a lack of literature reflecting the usage of different decision-making methods in one place, specifically in the software ecosystem context. These gaps in literature motivated authors to compare various MCDM methods. or this study, we compared four decision-making methods, namely AHP, ANP, TOPSIS, and ANN, due to their vast mention in the literature, which is evident in section 4, where these methods and their related studies are presented in detail. Along with these specific MCDM methods, a particular category named 'hybrid' is created, where a combination of one or more of these methods is applied along with fuzzy techniques.

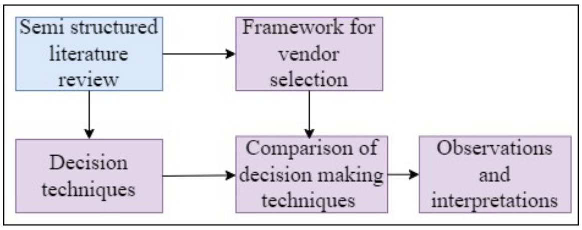

Figure 1. Methodology followed to conduct the study

A semi-structured literature review is carried out to compare these MCDM techniques (Figure 1). As an outcome of the literature review, various studies were extracted, as depicted in Tables 1-5. Studies older than the year 2010 are excluded to extract recent insights on these techniques. Additionally, the literature review supported the formation of a requirement framework for decision process of selecting vendors in the software ecosystem. After acquiring knowledge of the requirement framework and investigating different techniques, a comparison of decision-making methods in the given context is drawn, which led to various observations and interpretations for future work.

3. Requirement Framework for Selection of Vendors in the Software Ecosystem

This section details the requirements of the decision-making process for software vendor selection in the software ecosystem. Figure 2 shows the framework designed for selecting vendors and associated requirements to compare different decision-making techniques against it. These requirements are inspired by the semi-structured literature survey conducted by the authors in studies [1], [24]. This framework has four main requirements enlisted for effective decision-making in the software ecosystem, as described in Figure 2. In addition to these specific requirements, it is also important to note that simplicity and ease of use of MCDM techniques also play a vital role towards their adaption by practitioners.

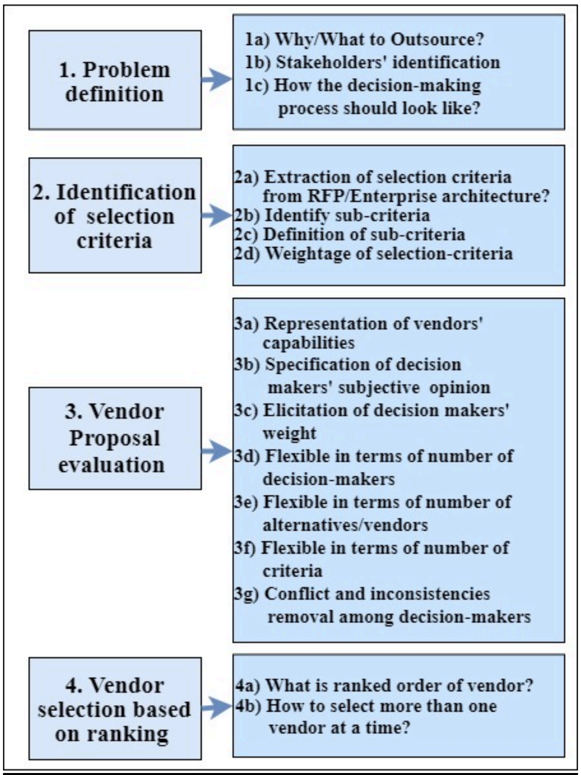

Figure 2. Requirement framework for decision-making for vendor selection in the software ecosystem

3.1. Problem Definition

Even though there are various models [20], [24] for decision-making, they often overlook the challenge of defining the decision problem itself, which is vital to analyse the 'As-Is' scenario of an organisation in order to identify the need for improvements in the business process and digital innovation [25], [26]. Further, there is a need to analyse the sociotechnical conditions within organisational contexts since focusing solely on limited optimisation risks neglects the complexities of organisational reality and its goals [27].

3.2. Identification of Selection Criteria

Selecting the most crucial factors or criteria for a decision is often the most challenging aspect of decision-making [32]. Those unfamiliar with the subject may be confused about what and how to incorporate it. Arranging those criteria helps to overview the problem and assesses the priority of the level [11], [28]. Further, the decision-making technique should provide means for the identification and definition of sub-criteria, which helps decision-makers understand the selection criteria better [36], [37]. All selection criteria might not be of similar importance in real scenarios; thus, it is also essential that the weights of selection criteria are taken into consideration. In a nutshell, a decision-making technique should be able to provide means: a) to extract selection criteria from request for proposal (RFP) or enterprise architecture? b) to identify and define sub-criteria, and c) to accommodate different weightage of selection-criteria.

3.3. Vendor Proposal Evaluation by Decision-Makers

Effective vendor proposal analysis and selection in ecosystems is an iterative process. The iterative nature of the process demands experience, requiring significant time and effort. Each company in the ecosystem repeats this process for every project. However, authors note a lack of standardization to formalise the process and tasks. According to C. Sanin *et al.* [29], storing experienced knowledge and information efficiently is crucial. This efficient storage enables smoother decision-making by eliminating redundant tasks and saving efforts. Although it is understood that proper knowledge representation enhances the efficiency and quality of decision-making, effectively representing knowledge remains a challenge [29]. Thus, the chosen decision-making technique should be able to a) represent vendors' capabilities, b) provide specification of decision makers' subjective opinion, c) provide means to accommodate different expertise of decision makers, d) handle different numbers of decision makers, e) handle different numbers of alternatives/vendors, f) handle different numbers of criteria, and g) cope with conflict and inconsistencies that may persist between different DMs during the selection process.

3.4. Vendor selection based on ranking

Lastly, the given method should generate the ranking of the vendors according to their suitability against chosen selection criteria.

4. Decision-Making Techniques

This section details the different MCDM techniques and their utilisation in various studies.

4.1. Analytic Hierarchy Process

There exist multiple approaches for evaluating and selecting software project proposal based on analytic hierarchy process (AHP). AHP is a technique which is used for multi-criteria decision making (MCDM) that allows decision makers to structure complex problems using hierarchies so that alternative solutions can be evaluated based on a set of criteria [30]. AHP has proven effective in solving diverse decision-making challenges across numerous fields, including selecting appropriate vendors or suppliers (Table 1).

There are essentially three aspects to the AHP process. The first is the judicious selection of experts who can subjectively decide the criteria based on which pair-wise comparisons will be made so that the best alternative can be chosen. The second is following a robust methodology so that the experts' opinions can be recorded accurately and the criteria for making decisions can be identified. The third is the mathematical basis governing AHP's decision-making process.

The first aspect of AHP is successfully implemented in the research conducted by Niemcewicz [31], to choose the most appropriate cloud services provider.

The author suggests choosing specialists who have no prior relationship with the cloud services providers being viewed as alternatives so that the criteria based on which the pair-wise comparisons will be made are free from any bias. The second aspect of AHP is explored in the research by Tahriri *et al.* [32], which focuses on the application of the technique for the selection of the most suitable vendor in the context of a steel manufacturing plant. The authors provide a step-by-step approach including that of conducting interviews with the specialists so that these results can be used to choose the relevant criteria. The third aspect of AHP is elaborated in several studies [28], [33], [34]. The research conducted by Devi *et al.* [33], which successfully implements AHP to select the most appropriate vendor from several alternatives for supply chain management, explains the mathematical steps used in the decision-making process. Similarly, the studies conducted by Deretarla *et al.* [28] and Veni *et al.* [34], also focus on selecting suitable vendors in the context of supply chain management and provide details to explain the mathematical basis of AHP.

4.2. Analytic Network Process

Analytic network process (ANP) is an extension of AHP which allows decision makers to choose the best solution from a set of alternatives based on a set of criteria [34]. ANP can be decomposed into two broad aspects and has been used for several decision-making problems (Table 2).

Table 1. Studies utilising AHP for vendor selection in various contexts

AHP	Applied in	Number of alternatives	Number of selection criteria	Number of sub-criteria	Number of decision makers
[31]	Selection of Cloud computing provider	5	5	-	-
[32]	Steel manufacturing company	4	9	30	-
[33]	Vendor selection in supply chain	-	5	-	-
[28]	Vendor selection in supply chain	5	4	-	-
[34]	Suppliers in manufacturing firm	3	6	19	-

Note: Cells with '-'entry means that this data is not specified in respective study

Table 2. Studies utilising ANP for vendor selection in various contexts

ANP	Applied in	Number of alternatives	Number of selection criteria	Number of sub-criteria	Number of decision makers
[9]	Supply chain management in heavy equipment selection	-	5	17	-
[35]	Supplier selection in a manufacturing company	-	3	45	-
[36]	Business process outsourcing	-	6	35	-
[37]	Supplier selection problem	3	2	10	-

Note: Cells with '-' entry means that this data is not specified in respective study

Table 3. Studies utilising TOPSIS for vendor selection in various contexts

TOPSIS	Applied in	Number of alternatives	Number of selection criteria	Number of sub-criteria	Number of decision makers
[10]	Supplier selection in green management	-	-	-	-
[38]	Coal Industry	5	6	23	-
[39]	Manufacturing Industry	6	10	-	-
[40]	Raincoat manufacturing company	3	4	-	-

Note: Cells with '-' entry means that this data is not specified in respective study

Table 4. Studies utilising ANN for vendor selection in various contexts

ANN	Applied in	Number of alternatives	Number of selection criteria	Number of sub-criteria	Number of decision makers
[7]	Logistic supplier selection	-	-	-	-
[41]	Supplier selection	-	6	-	-
[42]	Supplier selection in automobile industry	4	5	-	-

Note: Cells with '-' entry means that this data is not specified in respective study

The first aspect is that of constructing the network comprising the goal, the criteria, and the alternatives while the second aspect is that of the mathematical basis which governs the decision-making process which includes the construction of different matrices. Similar to AHP, ANP performs pairwise comparisons between different criteria and alternatives. The results of these comparisons are stored in individual matrices which are then amalgamated and stored in super matrices. The super matrix information is used to derive the decisions in ANP. The construction of the network, including the identification of the clusters into which the criteria and alternatives can be grouped, is explained in detail in the research conducted by Gencer and Gürpinar [35]. In this study ANP is used to select the best supplier for an electronics-based company. Another research which delves into the details of the construction of the network consisting of the criteria and alternatives is the one by Syafei *et al.* [9] in which the authors use ANP to determine the best supplier for a specific company in Indonesia which specialises in heavy equipment. The second aspect of the formation of the super matrix is discussed in [36] where ANP is used in the context of business process outsourcing. The research conducted by Bayazit [37] provides a complete process of ANP as it provides details on both aspects of forming a network as well as constructing a super matrix by using the decision-making process in the domain of supply chain management.

4.3. Technique for Order of Preference by Similarity to Ideal Solution

Technique for order of preference by similarity to ideal solution (TOPSIS) is an MCDM technique which evaluates the alternatives by comparing them with the ideal solution [43].

In this technique, the geometric distance is computed between a particular alternative and the positive ideal solution as well as the negative ideal solution. The alternative which is separated by the least distance from the positive ideal solution and has the most distance from the negative ideal solution is the most appropriate choice. Like other decision-making techniques, TOPSIS has been used across several domains including that of selecting the best vendor or supplier (Table 3).

The research conducted by Jain *et al.* [44] which addresses the problem of vendor selection in the Indian automobile industry, in [10] authors focus on choosing a supplier who can fulfil the environmental and sustainable goals of the organisation, Wu and Yang [38] explored the selection of a sustainable supplier in the coal industry, and the research conducted by Vimal, Chaturvedi and Dubey [39] which addresses the selection of vendors in the manufacturing industry. The study [40] differs from all the other studies as it cites existing literature as the basis for choosing the criteria and alternatives in its attempt to select the best vendor for a raincoat manufacturing company.

4.4. Artificial Neural Network

Artificial neural networks (ANNs) are machine learning models which take inspiration from the structural as well as functional attributes of the human brain [45]. ANNs have several layers with interconnected nodes which are designed to mimic the function of neurons. There are different varieties of artificial neural networks which can be used for decision-making. One such variety is that of feedforward neural networks which are the simplest types of artificial neural networks in which information only flows from the input to the output [46].

The other variety is that of backpropagation neural networks on which feedforward neural networks are additionally trained with the help of methods such as gradient descent so that the weights in the network can be adjusted and the error can be minimised [47].

For the selection of vendors, neural networks which are trained with backpropagation are used most widely (Table 4). In study conducted by Wu *et al.* [41] the best logistics supplier is chosen with the help of a backpropagation neural network and so does the research carried out by Cheng-dong *et al.* [7], the difference being that the latter chooses the third logistics supplier for the company while the prior chooses the primary logistics supplier. The research conducted by Wu *et al*. [41] and in research [7] backpropagation neural network is used to select the best vendor, however, they do so in the context of supply chain management. The research conducted by Asthana and Gupta [42] differs from the rest in that it only uses a feedforward neural network, albeit in conjunction with genetic algorithms, to select the most suitable vendor for organisations in the Indian market.

4.5. Hybrid Techniques

In the context of vendor selection, fuzzy techniques are generally used in an integrated manner; they have been combined with both AHP and TOPSIS extensively in the past. Fuzzy AHP (FAHP) is used in the process of decision-making by including fuzzy numbers in the matrix which is constructed for pairwise comparisons. FAHP is implemented in several studies which focus on finding the best vendor.

The research by Tang and Fang [8] make the decision regarding the best vendor in the context of supply chain management with the help of FAHP. The research by Bhat *et al*. [48] uses the decision-making method to choose the best supplier of vending carts. The research conducted by Nazim [11] contrasts the use of FAHP and FTOPSIS for the selection of the best software requirements and finds that both the methods yield comparable results. Other related studies are briefed in Table 5.

5. Comparison of MCDM Techniques and Discussion

This section addresses the set research question for this study by providing reflections on different MCDM techniques against the requirement framework described in section 3. Table 6 summarizes the insights and interpretations of the requirements described in section 3. These interpretations are drawn based on the knowledge gained from the related studies discussed in section 4 and summarised in Table 1-5. Thus, this section provides a reflection on which requirements of the decision-making process in the software ecosystem will be fulfilled if a particular MCDM technique for software vendor selection is chosen.

It is observed that the different studies utilising a MCDM technique discussed in section 4 do not focus on defining the decision-making problem itself. The crucial details of vendor selection which is to define and fixate the requirements are missing. For the same reason 'Problem Definition' row in Table 6 shows no evidence for this requirement with any of MCDM techniques. Rather every decision-making technique focus on finding the best alternative out of potential one.

Table 5. Studies utilising hybrid techniques for vendor selection in various contexts

Hybrid	Techniques	Applied in	Number of Alternatives	Number of Decision Criteria	Number of SDC	Number of decision makers
[8]	Fuzzy AHP	Supply chain vendor selection	4	7	-	-
[49]	Fuzzy AHP	ERP package	-	4	10	-
[50]	Fuzzy AHP	Model for realising government befits	2	13	73	3
[51]	Fuzzy AHP	Measuring maturity of Information security	-	17	35	3 groups of DMs
[52]	Fuzzy AHP	Selection of most suitable firm	3	3	11	-
[53]	Fuzzy AHP	Data warehouse selection	3	16	-	-
[44]	Fuzzy AHP and TOPSIS	Indian Automotive Industry	3	8	-	-
[11]	Fuzzy AHP and Fuzzy TOPSIS	Software requirements selection problem of an institute examination system	-	4	-	2
[54]	Fuzzy AHP and TOPSIS	Human resources and technology	9	8	23	-
[55]	Fuzzy AHP and TOPSIS	Assessment of usable security in web-applications	2	10	8	-
[56]	AHP and TOPSIS	Evaluation and selection of mobile health applications	10	9	28	3
[57]	Fuzzy AHP and TOPSIS	Evaluation of hotel websites	5	5	19	13
[58]	Fuzzy AHP and TOPSIS	Supplier selection	5	5	-	-

Note: Cells with '-' entry means that this data is not specified in respective study

Table 6. Decision-making techniques against requirement framework in software ecosystem

Context Requirements		**Decision-Techniques**				
		AHP	**ANP**	**TOPSIS**	**ANN**	**Hybrid**
1. Problem Definition	1a) What to outsource?	-	-	-	-	-
	1b) Stakeholders/DMs	-	-	-	-	-
	1c) Activities	-	-	-	-	-
2. Identification of selection criteria	2a) Extraction from RFP (request for proposal)	-	-	-	-	-
	2b) Identify sub criteria	-	-	-	-	-
	2c) Define sub-criteria	✔	✔	✔	-	✔
	2d) Weightages of criteria	✔	✔	✔	✔	✔
3. Vendor proposal analysis	3a) Representation of vendor capability	✔	✔	✔	✔	✔
	3b) Subjective opinion of DM	✔	✔	✔	✔	✔
	3c) Weightage to DMs	-	-	-	-	-
	3d) Number of Decision makers supported	-	-	-	-	✔
	3e) Alternative supported	✔	✔	✔	✔	✔
	3f) Criteria supported	✔	✔	✔	✔	✔
	3g) Conflict and inconsistencies removal	-	-	-	-	-
4. Vendor selection	a) Ranking of vendors	✔	✔	✔	✔	✔
	b) Dependencies between vendors/Alternatives	-	✔	-	✔	-

Note: Cells with '-' entry means that this data is not specified in respective study

As evident from Table 6, all the decision-making techniques fulfil the requirement 'Identification of selection criteria'. This interpretation is drawn from Tables 1-5, as one or more studies shows how these techniques are utilised to identify the selection criteria and their weights in various contexts. Additionally, none of the studies employing these methods addressed how sub criteria should be identified. Further, only a few studies utilising AHP, TOPSIS, and ANP and hybrid techniques showed how to define sub criteria and how many sub-criteria have been considered to rank vendors, unlike studies utilising ANN. Further, these decision-making techniques can represent vendor's capabilities effectively (Tables 1-5, column showing number of vendors). Often pair wise matrix is used for the same. Additionally, fuzzy methods are used on top of these techniques to incorporate the subjectivity of decision makers. Although every decision-making technique is capable of incorporating subjectivity of decision makers, but Fuzzy TOPSIS requires less subjective judgment by decision makers compared to fuzzy AHP as interpreted in the study [11].

Additionally, it is observed that studies utilising these techniques discuss on how to handle different number of alternatives, criteria, sub-criteria but only few studies [11], [49], [50], [56], [57] are found which detailed how different group of decision-makers can impact the overall ranking of the alternatives and most of these studies are found to be hybrid techniques (Table 5).

Further, limited research articles utilising these techniques discuss on how to handle the conflicts and uncertainties between decision makers which may prevail during the decision making process [16], [1].

Every decision-making technique provides ranking of vendors/alternatives at the end. Additionally, ANN and ANP can handle dependencies between selection criteria and alternatives. In ANP, they are considered as nodes or clusters, and pairwise comparisons can be made among these nodes whenever a relationship exists between them. Consequently, when using ANP, the selection of an alternative may not solely depend on the identified criteria but can also be influenced by other potential alternatives. This characteristic makes ANP better suited for tackling more intricate decision-making problems where criteria and alternatives are interdependent, as opposed to situations where they are independent, as seen in AHP. Hence ANP can handle dependencies between vendors/alternatives if there are any unlike AHP.

Considering the requirement framework and the Table 6, it can be said that it is of utmost importance to begin by establishing a clear and well-defined framework for the decision problem itself. While problem structuring methods, as proposed by Rosenhead and Mingers *et al.* [60], and group decision-making techniques, as discussed by Wright and Goodwi [61] , underscore the significance of defining the decision problem, they may lack precise modeling concepts.

A modeling language that articulates decision processes within an organizational context can serve as a valuable cornerstone. Such a language allows for the continuous and systematic analysis and enhancement of decision processes across various contexts and problem domains [22]. Moreover, conceptual modeling provides an 'As-Is' representation of the current state of affairs, enabling the identification of areas for improvement within business processes. This, in turn, supports an enterprise's journey towards digital transformation [26], [59]. Thus, there is a need to introduce and incorporate modelling languages on top of these MCDM techniques to define the decision-making problem itself.

AHP is used for measuring both qualitative and quantitative attributes, by prioritizing the alternative in the hierarchy. In contrast to AHP, which follows a clearly defined top-down approach, starting from the goal, and moving to the alternatives with pair-wise comparisons limited to the identified criteria, ANP treats both criteria and alternatives equally. TOPSIS is similar to both AHP and ANP in that criteria and alternatives have to be first determined before the decision-making process can continue. The second aspect of TOPSIS is that of mathematical calculations. The positive and negative ideal solutions are determined which are then used as a reference point to which the geometric distances of each solution are computed. Studies which implement TOPSIS are extremely comprehensive in their detailing of the decision-making process. Although they do not provide a detailed explanation on how to determine the different criteria and alternatives, they list these factors and discuss the mathematical aspects in thorough detail. Identifying the selection criteria for a decision constitutes a formidable challenge within the realm of decision-making. However, no study utilising these decision-making techniques discussed on how the selection criteria should be extracted and which software artifacts might be the source of these selection criteria. Therefore, there is a need to map selection criteria with software requirements. There should be a defined measure to extract these selection criteria, and the sources should be identified which influence these selection criteria.

Further, there can be more than one decision makers in decision-making process in real scenarios. Hence, further investigation is required to scale the number of decision-makers and to incorporate the expertise of different set of decision-makers in this decision-making process. AHP, when used for the selection of the best vendor shows how the process, can be extremely time-consuming because of the extremely high number of pair-wise comparisons which needs to be made in the process [28], [34].

A similar issue of being time-consuming is observed in ANP which needs to construct an elaborate network comprising different criteria and alternatives before a decision can be made [35]. The process of calculating the geometric distance in TOPSIS also makes it a time-consuming process [10], [44]. ANNs are also slow and lengthy decision-making processes as they need extensive training before, they can be used to select vendors [7], [41].

All MCDM discussed here significantly increase the time complexity of processing the data in one way or another. The subjective nature of these MCDM techniques, by which experts determine the relative importance of the criteria/alternatives in AHP, ANP, and TOPSIS [38] make these methods prone to errors. Additionally, since FAHP and FTOPSIS are extensions of AHP and TOPSIS, they are also subjective in nature and can be prone to human errors. It is noted that ANNs do not face the problem of having to rely on a subjective method of assigning weights as there are optimisation techniques such as gradient descent which can adjust the weights in the training phase so that the issue of subjectivity and bias can be eliminated. Fuzzy techniques introduce a level of complexity to the decision-making process which requires a high level of expertise to be successfully implemented unlike the other MCDM processes. The complexity of the fuzzy technique also makes it lack transparency, and it cannot be understood easily by people who are not well-versed with fuzzy logic. Incorporating fuzzy methods with MCDM reduces the issue of subjectivity that is faced during decision making process and can reduce possible errors and uncertainties however special training is required for individual to effectively utilise fuzzy logic.

Unlike AHP which is a clearly defined top-down process from the goal to the alternatives in which pair-wise comparisons are only made between the various criteria identified, ANP treats the criteria as well as the alternatives in an equal manner and views them as nodes/clusters. Each of these nodes can be compared in a pair-wise manner if there is a relationship which exists between them. Hence, the choice of an alternative through ANP may not only be governed by the criteria which are identified, but also by other potential alternatives. This property makes ANP more suitable for more complex decision-making problems such as ones in which the criteria and alternatives are not independent of each other as compared to AHP. On the other hand ANP and ANN can be computationally expensive as it takes into consideration the interdependencies which exist between the criteria as well as the interdependencies which exist between the alternatives [36].

ANNs can also be computationally expensive as they must process a large amount of data so that decisions can be made [7]. ANP and ANN are more suitable for decision-making problems where criteria and alternatives are interdependent, although these come with additional expense.

6. Conclusion

There are several challenges in utilizing multi-criteria decision-making problems. Every method has its own advantages and limitations. Hence, in this research, five different decision-making techniques are first analysed in different contexts by extracting the information from the literature. The insights which were generated from these studies were used to investigate if they would be appropriate for selecting vendors in the context of a software ecosystem where organisations would be looking to select the most suitable vendor based on how well they are aligned with the needs of the decision-making process related to software vendor selection. To do the same, a requirement framework is designed.

Benefits and drawbacks are noticed for each of the techniques. It was observed that the most prevalent drawback of these decision-making techniques is that they are subjective, which can lead to bias and errors. Also, these decision-making techniques lacks details on how to define the problem itself, which gives rise to the need to incorporate the modelling languages on top of these decision-making techniques. Furthermore, there is a lack of available literature which discusses how more than one number of decision-makers and different sets of decision-makers carrying different expertise can be considered towards effective decision-making. Additionally, there is a need to take measures for conflict resolution between different decision makers on top of these MCDM techniques. Further, it is observed that ANN and ANP can be used for decision making in complex scenarios, due to their capability of handing interdependence between alternatives and selection criteria. However, due to its comparative ease of use, AHP can serve better in scenarios where decision-makers are not experienced or past data to train the ANN or ANP models is not available.

In nutshell, it can be said that each technique has its positives and negatives. For simple problems AHP, TOPSIS can be considered along with fuzzy logic. ANP and ANN are suitable for the complex decision problems where criteria and alternatives are interdependent. However, these methods should have a modelling language on top of that to define decision problem itself. Additionally, to identify and resolve conflicts during decision process further measures should be taken and investigated.

7. Implications, Limitations, and Future Work

This study serves research community through three folds by a) providing detailed yet compact information about utilization of various MCDM techniques in different decision-making contexts, b) defining specific requirements of software vendor selection in software ecosystem, c) providing inferences and reflection on different MCDM techniques by comparing and investigating those against the set requirements of decision-making in software ecosystem.

This study will serve as the basis for researchers who are interested in the utilisation and optimisation of decision-making techniques in software vendor analysis and selection since this study provides necessary information in one place. Further, this study can support practitioners in understanding the decision-making techniques and their implications on the overall decision-making process in their organization. This study will help practitioners know the positives and negatives and additional efforts needed to incorporate any particular decision-making technique in their decision-making process.

Every decision-making technique has a unique set of advantages and disadvantages. There is no black-and-white approach which can be undertaken when it comes to selecting the best technique, which is why organisations need to evaluate themselves internally and consider the trade-off between the positives and the drawbacks with respect to their own goals before a successful choice of a decision-making technique can be made. Also, hybrid techniques can be utilised to harness positives of different decision-making techniques. In addition, this study will open up new research direction for improvements and required standardisation needed in decision-making processes in the software ecosystem.

However, the interpretations drawn in this study are based on the semi-structured review of literature which can impact replicability of the study due to obvious subjectiveness involved in the paper selection. In future a systematic literature review can be conducted to support the findings. Additionally, incorporating practitioners view by exposing them with finding can lead to interesting insights in the same direction. Further, for future work we aim to explore different modelling techniques to support decision making process, to address the major research gap found in this study. Additionally, we plan to initially optimize AHP by incorporating inconsistency and conflict removal measure to address one of the requirements of decision-making process identified in this study.

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