SYSTEMATIC SELECTION OF BLOCKCHAIN PLATFORMS USING FUZZY AHP-TOPSIS

Shahr Banoo Muradi[1], Yin Kia Chiam[2*]

[1,2]Department of Software Engineering, Faculty of Computer Science and Information Technology, Universiti Malaya, 50603 Kuala Lumpur, Malaysia

Email: banoomuradi@gmail.com[1], yinkia@um.edu.my[2*] (corresponding author)

DOI: https://doi.org/10.22452/mjcs.vol36no2.1

ABSTRACT

Various businesses and industries such as financial, medical care management, supply chain management, data management, Internet of Things (IoT) and government supremacy, have been using blockchain technology to develop systems. During the selection of blockchain platforms, many criteria need to be taken into account depending on the organization, project and use case requirements. This study proposes a systematic selection method based on the Fuzzy AHP-TOPSIS approach which compares and selects alternative blockchain platforms against a set of selection criteria that cover both features and non-functional properties. A case study was conducted to evaluate the applicability of the proposed selection method. The proposed selection method which consists of three main stages was applied for the comparison and selection of the most appropriate blockchain platform for two projects. In the case study, three blockchain platforms were selected and ranked for each project based on selection criteria derived from the project requirements. Both project representatives showed strong agreement with the applicability aspects of the proposed selection method. It is concluded that the proposed selection criteria and selection method can be applied practically to support the decision-makers in blockchain platform selection for real-world projects.

Keywords: blockchain, blockchain platforms, multi-criteria decision-making, selection method, fuzzy AHP, fuzzy TOPSIS

1.0 INTRODUCTION

Blockchain has gained popularity owing to providing a reliable distributed architecture [1, 2] for any sort of business occurrence. Growingly, various high-tech manufacturing companies have become mindful of blockchain network applications in their software products [3, 4, 40]. To select the most appropriate blockchain platform, multiple criteria, specifically functionality, amenability, and interoperability of the platform to the current software product need to be assessed. The decision-making process is a difficult task since software developers are not skillful in every discipline.

Choosing the right blockchain platform is considered a challenging selection process because it involves complex, multi-criterion problems [5] whose objectives may conflict. Furthermore, the excessive amount of information with conflicting objectives in a multi-attribute problem is beyond the capability of the human brain [6] and needs a sufficient selection method. With an increment in the number of decision-makers, alternatives and features, analysis becomes perplexing and difficult to decide. Consequently, there is a need for a decision model for blockchain platform selection [3].

Multi-criteria decision-making (MCDM) provides decision-makers with the ability to meet variegated decision criteria and multitudinous alternative problems to offer a solution to real-life problems which involve several criteria analyses [7]. There are numerous studies on blockchain comparison frameworks based on benchmarking experiments, but the suggested frameworks are not subject to a rigid mathematical foundation [8].

Blockchain platform selection involves the comparison of numerous criteria and features against different existing blockchain alternatives. Thereby it is considered an MCDM problem. Since the selection of the most suitable blockchain platform involves both features and quality attributes, a single MCDM technique is not always sufficient to identify the best-fitting blockchain platform, therefore a need to apply the integrated approach exists to solve this problem. A few studies have used MCDM techniques like Analytic Hierarchy Process (AHP), and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) in their proposed approaches for the blockchain platform selection problem, but none of them used a combination of MCDM techniques. An integrated approach such as Fuzzy AHP-TOPSIS can overcome the limitations of one MCDM technique with another MCDM technique.

In this research, a set of evaluation criteria that include both features and non-functional properties (including quality attributes) that can be considered during the selection of blockchain platforms for different types of projects, applications and use cases was identified to help other researchers, blockchain practitioners and decision-makers in the selection of blockchain platforms based on their project requirements. A systematic selection method of blockchain platforms using an integrated MCDM approach, the Fuzzy AHP-TOPSIS Blockchain Platform Selection Method (FAT-BPSM) is proposed for comparison and evaluation of different blockchain platform alternatives. This study focuses on the selection of open-source Blockchain platforms of any type (i.e., permissionless, permissioned, public, private) to support decision-makers to select appropriate blockchain platforms for their projects and software products. A case study was conducted to evaluate the applicability of FAT-BPSM for two projects in an organization.

The rest of the paper is organized as follows. Section 2 describes the studies related to this research. Section 3 presents the list of open-source blockchain platforms and selection criteria that are used in this research. Section 4 describes the proposed method, FAT-BPSM. Section 5 shows the evaluation of the proposed method using a case study and discussions of evaluation results. Finally, the last section concludes the study.

2.0 RELATED WORK

This section reviews research studies that propose a solution for blockchain platform selection and clearly explain the criteria used in the comparison and evaluation. Table 1 presents the analysis of these research studies based on six aspects. ‘Proposed solution’ refers to the work proposed by the researchers to support the comparison and selection of blockchain platforms. ‘Decision-making technique’ refers to the decision-making approach that has been applied to select blockchain platforms (e.g. Benchmarking, Boolean Decision Tree (BDT) and MCDM methods). ‘MCDM’ indicates whether the proposed solution is based on a multicriteria decision-making method. ‘Quality attributes’ denote whether quality attributes are considered for selection and whether the type of quality attributes are domain-specific (i.e. blockchain platform) or refer to ISO standards. ‘Criteria’ and ‘Alternatives’ stand for the number of evaluation criteria and the number of alternative platforms included for comparison and selection.

Among the selected studies, P1 to P6 [9-14] proposed solutions such as evaluation framework, anatomy, matrix and comparative analysis based on benchmarking techniques to assist in the decision-making process. These studies applied benchmark experiments in their studies to compare the blockchain platforms. However, performance and security tests are time-consuming and difficult for novice decision-makers who are unfamiliar with blockchain platforms.

These five studies (P10, P11, P12, P13 and P14) [1, 16, 2, 17, 18] introduce a BDT-based scheme for determining which type of database is appropriate such as public permissionless blockchain, distributed database, and central database. In BDT-based approaches, the number of criteria is limited (i.e., under ten), since processing the large decision trees is time-consuming and complicated. BDT-based approaches suggest one solution at the end of each evaluation. Moreover, decision-makers cannot prioritize decision criteria based on their preferences.

On the other hand, P7, P8, P9 and P15 [5, 8, 15, 3] proposed systematic selection approaches based on MCDM approaches. Most studies pointed out that MCDM methods can be applied to evaluate and compare a collection of blockchain platforms against each other. P8 [5] proposed an AHP model using a set of fixed VECTOR criteria for calculating weights and priorities to compare the Bitcoin cryptosystem with other common internet transaction systems based on informed judgements [8]. VECTOR criteria are derived from six English words (V = Vulnerability, E = Ease of Execution, C = Consequence, T = Threat, O = Operational-Importance, R = Resiliency). In this study, only qualitative types of criteria can be represented by fixed VECTOR criteria. Other common criteria relevant to online transaction systems, such as authentication, authorization, confidentiality, integrity and non-repudiation, and availability need to be used as additional criteria to further validate the results of the proposed hybrid AHP model. One of the major drawbacks of the proposed hybrid model is its applicability limitation to certain multi-criteria decision-making problems related to information security risks and IT solutions. In P9, the Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS) method is used for alternative ranking. A key problem with traditional TOPSIS is its inability to issue criteria weights and perform consistency checks on judgements [19]. Hence the entropy method is used for the calculation of the different indicators’ weights in the study. P7 and P15 applied the weighted sum model (WSM) in their studies. The weighted ranking system in P7 helps to calculate the blockchain’s benefit based on user-defined weights and score assignments.

P15 [3] proposed decision support systems (DSS) and WSM to produce a short-ranked list of feasible blockchain platforms. The weighted WSM is suitable for simple problems, as it supports single-dimensional problems. WSM allows the comparison of the alternatives by assigning scores, and then using these scores, standard values are generated for the alternatives under consideration. The major criticism of the WSM is the simplicity of the method which only supports single-dimensional decision-making problems as compared to MDCM such as AHP which can support both single- and multi-dimensional decision-making problems [20].

Table 1: Studies that carried out research related to the blockchain platform selection

ID	Reference	Proposed solution	Decision-making technique	MCDM	Quality Attributes	Criteria	Alternatives
P1	[10]	Framework	Benchmarking	No	Domain-specific	7	3
P2	[11]	Anatomy	Benchmarking	No	Not defined	3	6
P3	[12]	Reference for selection based on PRISMA	Benchmarking	No	Not defined	21	10
P4	[9]	Comparative analysis using a set of criteria	Benchmarking	No	Domain-specific	8	5
P5	[13]	Evaluation Framework	Benchmarking	No	Not defined	4	16
P6	[14]	Taxonomy, Comparative analysis	Benchmarking	No	Domain-specific	13	10
P7	[5]	Framework	WSM	Yes	Domain-specific	8	4
P8	[8]	Hybrid evaluation model	AHP	Yes	Domain-specific	6	4
P9	[15]	Evaluation model	TOPSIS	Yes	Domain-specific	14	30
P10	[1]	Requirements-driven methodology with flow diagrams	BDT	Yes	Domain-specific	8	4
P11	[16]	Framework with decision flow	BDT	Yes	Domain-specific	6	6
P12	[2]	Structured methodology with flow chart	BDT	Yes	Domain-specific	6	4
P13	[17]	Vademecum with decision tree	BDT	Yes	Domain-specific	17	7
P14	[18]	Decision scheme model	BDT	Yes	Domain-specific	9	8
P15	[3]	Decision model	DSS and WSM	Yes	ISO/IEC 25010	121	28

Most of the related studies often focus on one type of criteria, either features or non-functional properties (quality attributes). Both features and non-functional criteria (quality attributes) are rarely used in combination when comparing different blockchain platforms. Only a few studies used MCDM techniques and rigid mathematical foundations like WSM, AHP and TOPSIS in their proposed framework for the blockchain platform selection problem.

In a fuzzy multiple-criteria decision-making (FMCDM) problem, the fuzzy set theory provides the advantage of easily using linguistic terms for alternative evaluation [21, 41]. Many studies have compared different MCDM techniques based on their perspectives and theories [19, 21, 22]. Referring to the comparison of studies that have applied MCDM techniques (Table 1), the authors usually used a combination of the AHP method with other MCDM techniques [19, 23-29] in their proposed decision-making process in different application domains. AHP can be used for weight calculation [6, 22] and TOPSIS is one of the most practical methods which helps identify the most suitable alternatives quickly [19]. In this study, Fuzzy AHP has been combined with Fuzzy TOPSIS to efficiently handle the fuzziness problem of the information involved in deciding the most suitable blockchain platform. To the best of our knowledge, none of the related studies for blockchain platform selection used a combination of MCDM methods to overcome the difficulties of one method with the other.

3.0 BLOCKCHAIN PLATFORMS AND SELECTION CRITERIA

There are divergent blockchain platforms which vary in terms of their application domain. A list of open-source blockchain platforms that have been included in this research as alternatives for comparison and selection is presented in the appendix. It is a list of 25 potential alternatives that can be used in the decision-making process for the selection of blockchain platforms because they are widely used and have good documentation for us to retrieve the information to develop the knowledge base.

Based on the analysis of the evaluation criteria of blockchain platforms, the evaluation criteria can be categorized into two main categories, namely functional (i.e. features) and non-functional (including quality attributes) properties. There are different features supported by different blockchain platforms. Blockchain features are subdivided as follows: blockchain network types, Consensus mechanisms, tokens, layers, cryptocontract, programming language, privacy/anonymity feature, interoperability, resilience, scalability, structure, and data model. In this research, a list of feature categories and criteria under each feature category was identified and shortlisted from existing studies to be used as selection criteria (see Table 16 in Appendix).

Some quality attributes are taken into account in existing studies to assess and select suitable blockchain platforms for their projects, applications or use cases. The quality attributes defined in System and Software Quality Models (ISO/IEC25010) are used to identify the main quality attributes that can be considered as evaluation criteria (i.e. Performance efficiency, Compatibility, Usability, Reliability, Security, Maintainability and Portability). Domain-specific non-functional criteria not covered by ISO/IEC25010 are product, supplier, cost, size, and privacy are included as well. Some domain-specific non-functional properties are mapped into the main quality attributes to ease the comparison of the quality attributes selected by the existing studies. Table 17 in the appendix shows the non-functional properties included as selection criteria in this study.

The information on the selection criteria, features and non-functional properties (including quality attributes) is collected based on the official website documentation, online resources, and white papers of these blockchain platforms. The following two mapping information contribute to the knowledge base to help decision-makers to refer to the features and non-functional properties (including quality attributes) of each blockchain information to make a comparison and evaluation. Mapping information for features and non-functional properties (including quality attributes) of each blockchain platform can be retrieved from this website: https://sites.google.com/um.edu.my/ykchiam/research/blockchain.

4.0 FUZZY AHP-TOPSIS BLOCKCHAIN PLATFORM SELECTION METHOD (FAT-BPSM)

This section presents the Fuzzy AHP-TOPSIS Blockchain Platform Selection Method (FAT-BPSM) proposed in this research. Section 4.1 describes an overview of FAT-BPSM. The details of each stage and step proposed in this method for conducting the decision-making process of the selection of appropriate blockchain platforms are explained in Sections 4.2 to 4.4.

4.1 Overview of FAT-BPSM

FAT-BPSM aims to help decision-makers to choose a suitable blockchain platform based on their project requirements. The method compares and evaluates the blockchain platform's features and quality attributes, and priorities are assigned to them according to the obtained weightage for each criterion. Fig. 1 illustrates an overview of the FAT-BPSM that consists of three main stages: (1) Pre-selection stage, (2) Selection stage, and (3) Final stage.

Before the decision-making process, there are a few pre-selection procedures to adhere to. To begin with the pre-selection stage, overall objectives or goals are defined. Requirements will be collected from project decision-makers to determine the selection criteria. After project decision-makers prioritized all the requirements, potential blockchain platforms will be shortlisted as possible solutions. Next, during the selection stage, the shortlisted Blockchain platforms will be included as alternatives that will be compared and evaluated in the integrated Fuzzy AHP-TOPSIS decision-making process. At the final stage, the proposed method will identify and select the most appropriate blockchain platform which fits project needs, amongst the alternatives. Section 4.2 to Section 4.4. describe each stage and step in the FAT-BPSM in detail.

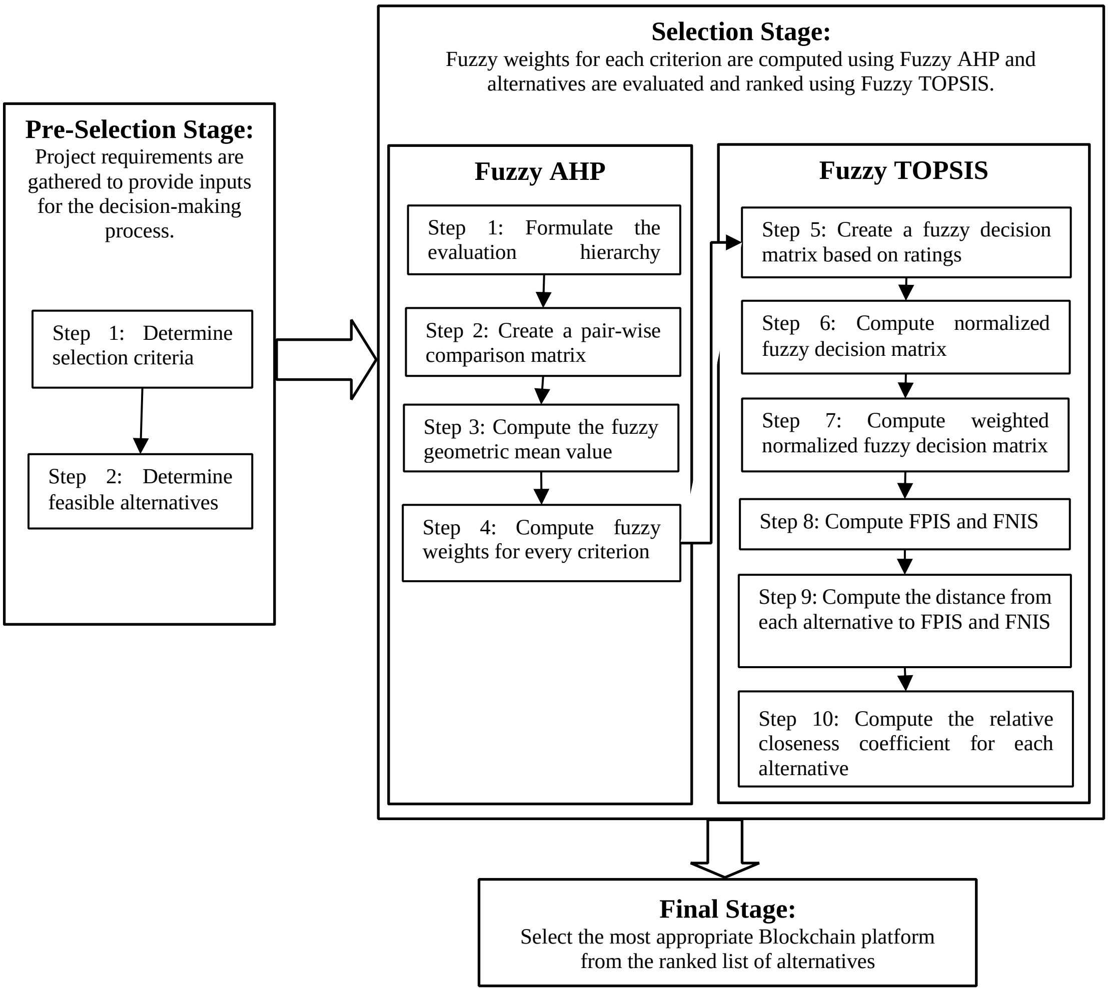

Fig. 1: Overview of the proposed FAT-BPSM.

4.2 Pre-selection stage

In the pre-selection stage of FAT-BPSM, project requirements are gathered to provide inputs for the decision-making process, i.e., blockchain platform features and non-functional properties (including quality attributes) for comparison and selection, and feasible alternatives (blockchain platforms) matching the specified features and quality requirements. The following steps are performed in the pre-selection stage:

4.2.1 Step 1: Determine selection criteria

The initial step of the proposed selection method is to identify the evaluation criteria used for the comparison and selection of the most appropriate blockchain platform based on user requirements. The key or desired features and non-functional properties (including quality attributes) of blockchain platforms are derived from the existing studies. Table 16 and Table 17 in the appendix show the list of selection criteria.

In this step, decision-makers specify their criteria requirements of the blockchain platform using the requirements prioritization technique, the Numerical Assignment Technique. This technique simplifies selection criteria analysis and prioritizes the requirements [30] to choose the best-matching blockchain platform for a project. The numerical Assignment Technique works by classifying requirements into different groups. Although the number of groups is arbitrary, three group divisions namely Optional, Standard, and Critical, are more frequently used [31]. Each project requirement can be assigned a numerical scale of 1 to 3 which indicates the level of importance [30] as follows:

- **Level 1 - Does not matter (Optional):** This means that the requirements in this group will not affect the success of the project and it is not necessary to be implemented in the current stage. They may be implemented in the next release.

- **Level 2 - Rather important (Standard):** This means that the project would be nice if the requirements in this group are considered.
- **Level 3 - Very important (Critical):** This means that requirements in this group must be contained in the project. The project would fail if these requirements were not delivered.

Table 2 illustrates a representation of how the ranking and classification can be done. All requirements based on features and non-functional properties that are categorized in the same level group (e.g. Level 3 – Very Important) will have equal priority, meaning that not any requirement has higher or lower priority than the other requirements in the same level group [31]. For example, Permissioned, Smart Contract and Availability have the same priority and are classified as very important requirements in the project by decision-makers. Features that are prioritized as very important (critical) will be used in step 2 to determine possible alternatives. The remaining criteria are to be used for comparison using Fuzzy AHP-TOPSIS.

Table 2: Requirements/criteria prioritization sample by decision-makers

Level of Importance		**Feature**	**Non-functional (Quality Attribute)**
3	Very Important (Critical)	Requirement 1 (Permissioned) Requirement 2 (Smart contract)	Requirement 3 (Availability)
2	Rather Important (Standard)	Requirement 4 (Asset-based tokens)	Requirement 5 (Interoperability) Requirement 6 (Reusability)
1	Does not matter (Optional)	Requirement 7 (Private) Requirement 8 (Consortium) Requirement 9 (Hard fork resistant)	

4.2.2 Step 2: Determine feasible alternatives

According to the literature review, numerous well-known open-source blockchain platforms are available in the market and can be included as potential alternatives that can be used in the decision-making process for the selection of the blockchain platform in this research. Shortlisted blockchain platform alternatives that will be used in this study are listed in the appendix. Blockchain platforms that are temporarily unavailable or have incomplete documentation during the study were excluded as feasible alternatives.

4.3 Selection stage

In this stage, blockchain alternatives are compared and evaluated against a set of selection criteria, to decide the best-suited blockchain platform for the projects under consideration based on project requirements. This structured integrated method, FAT-BPSM comprises 10 steps that are required for the comparison and selection of a blockchain platform according. Steps 1 to Step 4 are derived from Fuzzy AHP and Steps 5 to Step 10 are derived from Fuzzy TOPSIS [32, 33].

4.3.1 Step 1: Formulate the evaluation hierarchy system

Formulate the evaluation hierarchy system using prioritized features and non-functional (quality attributes) criteria and shortlisted platforms determined from the previous stage. The overall objective is to help a potential user to select the most appropriate blockchain platform based on project requirements. The selection criteria prioritized as "very important (critical)", "rather important (standard)" and "does not matter (optional)" are used for comparison using Fuzzy AHP-TOPSIS. Possible alternatives are listed from step 2 of the pre-selection stage.

4.3.2 Step 2: Create a pair-wise comparison matrix

In this step, decision-makers compare one criterion relative to other criteria using linguistic terms with the help of a relative importance scale. Fuzzification refers to the process of converting linguistic terms into the triangular membership function, $\mu_{\tilde{A}}(x)$ as seen in Eq. (1). As illustrated in Fig. 2, each fuzzy triangular scale has three values, namely, the lowest value (lower, l), the middle value (median, m), and the highest value (upper, u). The scale of relative importance with crisp numeric values and their corresponding triplet fuzzy numbers (l, m, u) is shown in Table 3.

$\mu_{\tilde{A}}(x) = \tilde{A} = \{\frac{(x-l)}{(m-l),\quad l\leq x\leq m,} \frac{(u-x)}{(u-m),\quad m\leq x\leq u,} 0, \qquad otherwise$
(1)

Two fuzzy numbers can be added and multiplied using Eq. (2) and (3):

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2)$$

$$= (l_1 l_2, m_1 m_2, u_1 u_2) \text{ for } l_1, l_2 > 0; m_1, m_2 > 0;\ u_1 u_2 > 0 \quad (3)$$

The reciprocal of the fuzzy number can be calculated using Eq. (4) :

$$\tilde{A}^{-1} = (l_1, m_1, u_1)^{-1} = (\frac{1}{u_1}.\frac{1}{m_1},\frac{1}{l_1}) \quad (4)$$

Subsequently, the pair-wise comparison matrix, $\tilde{A}$ for fuzzy AHP process are constructed based on the fuzzy triangular scale of the assigned linguistic term, which can be expressed mathematically as shown in Eq. (5) where n is the total number of criteria. A reciprocal value will be automatically assigned to the reverse comparison within the matrix. For example, if criteria 1 is "Strongly Important" than criteria 2, the decision maker will assign a triangular scale (6,7,8) in the $\tilde{a}_{12}$. On the other hand, the reciprocal value (1/8,1/7,1/6) will be assigned to the reverse pairwise comparison of criteria 2 to criteria 1, $\tilde{a}_{21}$.

$\tilde{A} = [1\ \tilde{a}_{21}\ \ \tilde{a}_{12}\ \cdots\ \ 1\ \cdots\ \ \tilde{a}_{1n}\ \tilde{a}_{2n}\ \ \vdots \vdots \ddots \vdots\ \tilde{a}_{n1}\ \tilde{a}_{n2}\ \cdots\ \ 1\ ]$
(5)

Where $\tilde{a}_{ij} = \{1, \quad i = j\ \tilde{1}, \tilde{2}, \tilde{3}, \tilde{4}, \tilde{5}, \tilde{6}, \tilde{7}, \tilde{8}, \tilde{9}\ \ or\ 1^{-1}, 2^{-1}, 3^{-1}, 4^{-1}, 5^{-1}, 6^{-1}, 7^{-1}, 8^{-1}, 9^{-1},\ \ i \neq j$

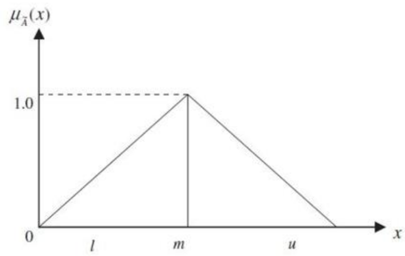

Fig. 2: The membership functions of the triangular fuzzy number (Sun, 2010).

Table 3: Linguistic terms and the corresponding triangular fuzzy numbers [34, 35, 36]

Saaty scale	Linguistic terms	Fuzzy Triangular Scale
1	Equally important (Eq. Imp.)	(1,1,1)
3	Weakly important (W. Imp.)	(2,3,4)
5	Fairly important (F. Imp.)	(4,5,6)
7	Strongly important (S. Imp.)	(6,7,8)
9	Absolutely important (A. Imp.)	(9,9,9)
2	The intermittent values between two adjacent scales	(1,2,3)
4		(3,4,5)
6		(5,6,7)
8		(7,8,9)

4.3.3 Step 3: Compute the fuzzy geometric mean value

In this research, Fuzzy AHP proposed by Buckley [37] is used to calculate the weights using geometric mean. The fuzzy geometric mean value $\tilde{r}_i$ for criteria is calculated using Eq. (6) which shows the fuzzy comparison value of criterion *i* to each criterion.

$$\tilde{r}_i = \left(\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{in} \right)^{1/n} \quad (6)$$

4.3.4 Step 4: Compute fuzzy weights for every criterion

The fuzzy weight for every criterion, $\widetilde{w}_i$ is calculated using Eq. (7):

$$\widetilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1} \quad (7)$$

By applying Fuzzy AHP, fuzzy weights for each criterion are obtained. These values are collected to proceed with the Fuzzy TOPSIS evaluation (Step 5 to Step 10).

4.3.5 Step 5: Create a fuzzy decision matrix based on ratings

In this step, decision-makers assign appropriate ratings to each shortlisted alternative platform for each criterion. The mapping information of features and non-functional properties (including quality attributes) collected for each platform is intended to help decision-makers to make judgemental values. Table 4 illustrates the linguistic terms for the rating scale of the alternatives and their corresponding triangular fuzzy numbers used in this research. A fuzzy decision matrix is created based on the ratings from decision-makers for each shortlisted alternative platform.

Table 4: Linguistic terms and triangular fuzzy numbers for alternative ratings [38]

Linguistic terms for alternatives ratings	Triangular fuzzy numbers
Very good	(9,10,10)
Good	(7,9,10)
Medium	(3,5,7)
Poor	(1,3,5)
Very poor	(1,1,3)

4.3.6 Step 6: Compute normalized fuzzy decision matrix

In this step, a normalized fuzzy decision matrix, $\tilde{R}$ is computed using Eq. (8). The normalized $\tilde{r}_{ij}$ and best-aspired level u_j^+ in the entire fuzzy decision matrix can be calculated for *i*th alternative with respect to the *j*th criterion using Eq. (9).

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{m \times n} \, where \; i = 1,2,\cdots,m; j = 1,2,\cdots,n \quad (8)$$

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^*}\right) \, and \; u_j^+ = max_i\{u_{ij} |\; i = 1, 2, \cdots, n\} \quad (9)$$

4.3.7 Step 7: Compute weighted normalized fuzzy decision matrix

In this step, a matrix known as the weighted fuzzy normalized decision matrix, $\tilde{V}$ is computed using Eq. (10)

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{n \times n} where \; \tilde{v}_{ij} = \tilde{r}_{ij} \otimes \widetilde{w}_j \quad (10)$$

4.3.8 Step 8: Compute Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS)

Two fuzzy numbers called Fuzzy Positive Ideal Solution (FPIS), A^+ and Fuzzy Negative Ideal Solution (FNIS), A^- are computed using Eq. (11) and Eq. (12):

$$A^{+} = (\tilde{v}_1^{+}, \tilde{v}_2^{+}, \cdots, \tilde{v}_n^{+}) \tag{11}$$

$$A^{-} = (\tilde{v}_1^{-}, \tilde{v}_2^{-}, \cdots, \tilde{v}_n^{-}) \tag{12}$$

$$where\ \tilde{v}_j^{+} = (1,1,1) \otimes \tilde{w}_j = lw_j, mw_j, uw_j \quad and\ \tilde{v}_j^{-} = (0,0,0), j = 1,2,\cdots,n$$

4.3.9 Step 9: Compute the distance from each alternative to the FPIS and the FNIS

The distance between the two fuzzy numbers *x* and *y*, *d(x, y)* is calculated using Eq. (13). The distance of each alternative from the ideal solution (FPIS), D_i^{+} and the gap between each alternative from the negative ideal solution (FNIS), D_i^{-} are computed using Eq. (14) and Eq. (15).

$$d(x, y) = \sqrt{\frac{1}{3}\left[(x_1 - y_1)^2 + (x_2 - y_2)^2 + (x_3 - b_3)^2\right]} \tag{13}$$

$$D_i^{+} = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^{+}),\ i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \tag{14}$$

$$D_i^{-} = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^{-}),\ i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \tag{15}$$

4.3.10 Step 10: Compute the relative closeness coefficient for each alternative

The relative closeness coefficient, CC_i for the *i*th alternative to the ideal value is computed using Eq. (16).

$$CC_i = \frac{d_i^{-}}{d_i^{*} + d_i^{-}} = 1 - \frac{d_i^{+}}{d_i^{*} + d_i^{-}}\ , i = 1,2,\cdots,m \tag{16}$$

A ranking of alternatives will be generated based on the relative closeness coefficient values computed in the previous step. The highest value will be ranked as one and the alternative with the lowest value will be ranked last.

4.4 Final stage

The final stage in the proposed selection method is to choose the most appropriate platform from the ranked list of alternatives being evaluated. According to the selection stage of FAT-BPSM, a ranked list of alternatives is obtained. Rankings are given in ascending order, in which the blockchain platform scores the highest value and is considered the most appropriate blockchain platform, fitting the project requirements and an alternative with the lowest value will be the least appropriate blockchain platform. The alternative which ranked number 1 is recommended as the most appropriate blockchain platform for the project.

5.0 CASE STUDY

A case study was conducted based on the guidelines proposed by Runeson and Höst [39] to evaluate the applicability of FAT-BPSM for two projects. In this research, the proposed FAT-BPSM method was applied in two projects to evaluate the applicability of the proposed method for the blockchain platform selection problem. Generally, complexities or issues in a particular research domain can be tackled and improved by analyzing practical events. The case study begins with case selection by choosing domains and real-world project contexts for the case study, followed by data collection and application of the proposed selection method, FAT-BPSM. Next, the proposed method is applied to the two projects and the results were analyzed to conclude if the proposed selection method can be applied to real-world projects.

5.1 Case selection

Two projects were selected from a science and research organization in Australia. Two blockchain experts are senior research scientists at the organization who participated in this case study. Each participant played the role of decision-maker for a project in the organization and provided project requirements to prioritize selection criteria and give ratings of selection criteria against alternative blockchain platforms to evaluate the applicability of FAT-BPSM in the selection of blockchain platform.

The first project, "Hydrogen Accreditation (HA)" aims to build a blockchain-based data platform for hydrogen certification. A trustworthy data platform is needed to support information sharing and business collaborations required to operate the hydrogen certification and associated supply chain of hydrogen manufacturing, transporting, storing, and consuming. Blockchain technology can be adopted to facilitate transparency and build stakeholder trust in the whole process.

The second project, "Measured Circular Economy (MCE)" aims to develop an innovative, connected packaging to waste system that connects brands and the enterprise's consumers that collaborate with the organization. The design of a blockchain-based data platform is part of the project. Circular Economy (CE) is redefining growth by decoupling economic activity from the consumption of finite resources to the continual use of resources for positive society-wide benefits. Blockchain technology can support immutable, transparent, and high-availability infrastructure for storing data and executing programs using smart contracts to manage consumer rewards, store traceability data and issue digital badges to MCE participants.

5.2 Data collection

Designing and preparing the materials for the applicability check is crucial to get more accurate evaluation results. Two questionnaires named "Project Requirement Gathering Questionnaire" and "Alternatives Rating Questionnaire" were designed to collect information needed to apply FAT-BPSM for selecting the most appropriate blockchain platform for each project given by the expert. The links to access these two online questionnaires were distributed to the experts via email.

The "Project Requirement Gathering Questionnaire" was designed using Google Forms to collect project requirements. In the questionnaire, each participant was required to provide project information by selecting and prioritizing the blockchain feature requirements according to the Numerical Assignment Technique. The "Very Important (Critical)" features can be used to shortlist the alternative blockchain platforms for each project.

The "Alternatives Rating Questionnaire" was designed using a Google Form in a structured way to collect evaluation ratings of each platform against the shortlisted selection criteria from the participants. The "Alternatives Rating Questionnaire" aims to collect judgmental values from the experts who play the role of decision-makers in their projects to give ratings for each shortlisted alternative based on the mapping information of non-functional criteria (including quality attributes). All the necessary information the participants needed to know when selecting and prioritizing their project requirements was given in the questionnaire (i.e., a description of selection criteria and information on blockchain platforms). Hence it will not cause any confusion or error during the application of the proposed FAT-BPSM in the selection of a blockchain platform for each project.

An online session was arranged through the Webex communication portal to get the two participants to familiarize themselves with the proposed method, FAT-BPSM. During the session, the application of the proposed method was explained in detail with examples. The questionnaires used in the study were presented to the participants to ensure they understand the instructions clearly. After the session, participants are provided with materials (i.e., presentation slides which included an introduction of the research, research objective, an overview of the proposed method and a step-by-step explanation of applying FAT-BPSM in the comparison and selection of blockchain platforms) to ensure that before the application of FAT-BPSM on the two projects, both participants have sufficient information about the proposed method to effectively participate in the case study. After the participants completed the "Project Requirement Gathering Questionnaire" forms, another questionnaire, the "Alternatives Rating Questionnaire" had sent to them to rate the possible alternatives for each of the non-functional requirements (including quality attributes) by referring to the mapping information (knowledge base).

Lastly, another online session was arranged to present the case study results to participants and an interview was conducted to collect their opinions. Besides, a "Post-evaluation Questionnaire" was designed to collect follow-up feedback from participants to evaluate the applicability of the proposed FAT-BPSM and suggestions for improvement.

5.3 Application of FAT-BPSM

This section describes the application of FAT-BPSM for the two projects in this case study. Section 5.3.1 to Section 5.3.3 describes the application of three stages (i.e. pre-selection, selection and final selection) to compare and select blockchain platforms for each project.

5.3.1 Pre-selection stage

When the decision-makers submit the project requirements, the pre-selection stage was conducted based on the two steps proposed in FAT-BPSM to determine selection criteria (step 1) and determine feasible alternatives (step 2). Table 5 shows 53 criteria (i.e., 10 very important features, 38 very important non-functional criteria and 5 rather important features) selected and prioritized by the first participant to compare and evaluate blockchain platforms for the HA project. On the other hand, 87 criteria (i.e., 6 very important features, 4 very important non-functional criteria, 18 rather important features, 25 rather important non-functional criteria, 22 optional features and 12 optional non-functional criteria) were selected and prioritized by the second expert for the MCE project (see Table 6).

Based on the "Very Important (critical)" features collected from project requirements, three alternative platforms were shortlisted for comparison. Three blockchain platforms namely Ethereum, JPMorgan Quorum and Hyperledger Fabric were shortlisted as feasible alternatives for the HA project. On the other hand, Ethereum, Stratis Azure Baas and Stellar were shortlisted as feasible alternatives for the MCE project.

Table 5: Criteria prioritization for the HA project

Level of Importance		Feature	Non-functional (Quality Attribute)
3	Very Important (Critical)	1. Permissioned 2. Application layer 3 Smart contract 4. Golang 5. Java 6. Privacy technologies 7. Enterprise system integration 8. On-chain transactions 9. Off-chain transactions 10. Data Computation and Storage	1. Time-behavior 2. Cost-efficiency 3. Co-existence 4. Interoperability 5. Appropriateness 6. Learnability 7. Accessibility 8. Availability 9. Fault tolerance 10. Recoverability 11. Confidentiality 12. Authenticity /Identity 13. Auditability 14. Modularity 15. Reusability 16. Modifiability 17. Testability 18. Upgradability 19. Sustainability 20. Adaptability/scalability of internal capacity 21. Installability 22. Replaceability 23. Usefulness 24. Comfort 25. Risk mitigation 26. Flexibility 27. Technology Maturity 28. Complexity 29. Support 30. Services offered 31. Market Capitalization/ Popularity in the market 32. Governance (development decisions, etc.) 33. Documentation 34. Development 35. Platform cost 36. Transaction fees 37. Block Size 38. Transaction size

2	Rather Important (standard)	1. pBFT 2. dApp tokens 3. Asset-based tokens 4. Atomic swap 5. Cross-chain technology	(none)

Table 6: Criteria prioritization for the MCE project

Level of Importance		Feature	Non-functional (Quality Attribute)
3	Very Important (Critical)	1. Public 2. Permissioned 3. Application layer 4. Smart-contract 5. Enterprise system integration 6. Key-value	1. Appropriateness 2. Availability 3. Technology maturity 4. Complexity
2	Rather Important (Standard)	1. PoS 2. DPoS 3. pBFT 4. PoA 5. Naïve tokens 6. Asset-based tokens 7. Utility tokens 8. Solidity 9. Privacy Technologies 10. Cross-chain technology 11. Spam attack resistant 12. Sybil attack resistant 13. Instant transaction finality 14. On-chain transactions 15. Off-chain transactions 16. Sidechains 17. Data Computation and Storage 18. Account	1. Time-behavior 2. Cost-efficiency 3. Interoperability 4. Accessibility 5. Fault tolerance 6. Authenticity /Identity 7. Auditability 8. Modularity 9. Reusability 10. Modifiability 11. Upgradability 12. Adaptability 13. Usefulness 14. Comfort 15. Risk mitigation 16. Flexibility 17. Software License 18. Deployment 19. Support 20. Services offered 21. Documentation 22. Development 23. Platform cost 24. Transaction fees 25. Transaction size
1	Does not matter (Optional)	1. Private 2. Consortium 3. dBFT 4. Cryptographic tokens 5. Non-native Protocol token 6. dApp tokens 7. Protocol layer 8. Network layer 9. Virtual machine 10. Turing completeness 11. Python 12. Golang 13. Java 14. JavaScript 15. .Net 16. C++ 17. Zero-knowledge proof/protocol 18. zk-SNARK 19. Ring signatures	1. Co-existence 2. Learnability 3. Recoverability 4. Confidentiality 5. Testability 6. Sustainability 7. Installability 8. Replaceability 9. Special hardware requirement 10. Energy consumption 11. Governance 12. Block Size

		20. Hard fork resistant 21. Off-chain state channels 22. New communication patterns	

5.3.2 Selection stage

Steps 1 to Step 4 are derived from Fuzzy AHP. In step 1, the evaluation hierarchy systems were formulated for HA and MCE projects as illustrated in Fig. 3 and Fig. 4. Next, a pair-wise comparison matrix is created for each project (see Table 7 and Table 8) based on the comparison of criteria in pairs by assigning a relative importance scale after discussing it with decision-makers. Each criterion was compared with respect to other criteria using a scale of relative importance linguistic terms and the corresponding triangular fuzzy numbers presented in Table 3 (Step 2). In step 3, fuzzy geometric mean value r_i and fuzzy weights w_i were calculated for each criterion using equations 6 and 7 presented in Steps 3 and 4 (Section 4.3.3 to 4.3.5). The fuzzy geometric mean values and fuzzy weights are shown in Table 9 and Table 10.

Steps 5 to Step 10 are derived from Fuzzy TOPSIS. For feature criteria, the feature criterion was rated "very good" if the feature is supported by the blockchain platform and the feature criterion was rated "very poor" if the platform does not support the feature. Judgemental values rated by the participants for each of the non-functional requirements (including quality attributes) of each alternative were collected using the "Alternatives Rating Questionnaire".

In step 5, a fuzzy decision matrix was created based on ratings for every criterion given by both decision-makers in the "Alternatives Rating Questionnaire". Normalized and weighted normalized fuzzy decision matrices were calculated using equations 8, 9 and 10 presented in Steps 6 and 7 (Section 4.3.6 to 4.3.7). Next, FPIS and FNIS values were calculated using equations 11 and 12 presented in step 8 (Section 4.3.8). Table 11 and Table 12 present the weighted normalized fuzzy decision matrix, FPIS and FNIS values for both projects. Based on the FPIS and FNIS, the distance from each alternative to the FPIS, D^+ and the distance from each alternative to the FNIS, D^- were computed using equations 14 and 15 as presented in Step 9 (Section 4.3.9). Lastly, the relative closeness coefficient, CC_i for each alternative was calculated using equation 16 (Step 10, Section 4.3.10) and CC_i for all the alternatives will be used in the final stage to produce the alternative rankings shown in Table 13 and Table 14. Microsoft Excel spreadsheet was used to perform the calculations of Step 2 to Step 10 in the selection stage as described in Section 4.3. The complete calculations for HA and MCE projects can be accessed via the following two links:

- https://bit.ly/3REcBHG
- https://bit.ly/3B2XzEq

5.3.3 Final stage

In the final stage, a final ranked list of alternative blockchain platforms was recommended by FAT-BPSM for each project based on the closeness coefficient values (refer to Table 13 and Table 14). A meeting was carried out formally via the Google Meet communication portal to discuss the results obtained by the proposed FAT-BPSM for each project and evaluate the applicability of the FAT-BPSM in real-world projects. During the evaluation discussion session, the results of the blockchain selection were presented to the experts. Each expert gave comments about the results and provided feedback on the applicability and improvement of the FAT-BPSM. After the discussion session, the "Post-evaluation Questionnaire" was distributed to each expert via email to collect their final assessment on the applicability of FAT-BPSM. The data collected from this questionnaire were analyzed and presented in Section 5.4.

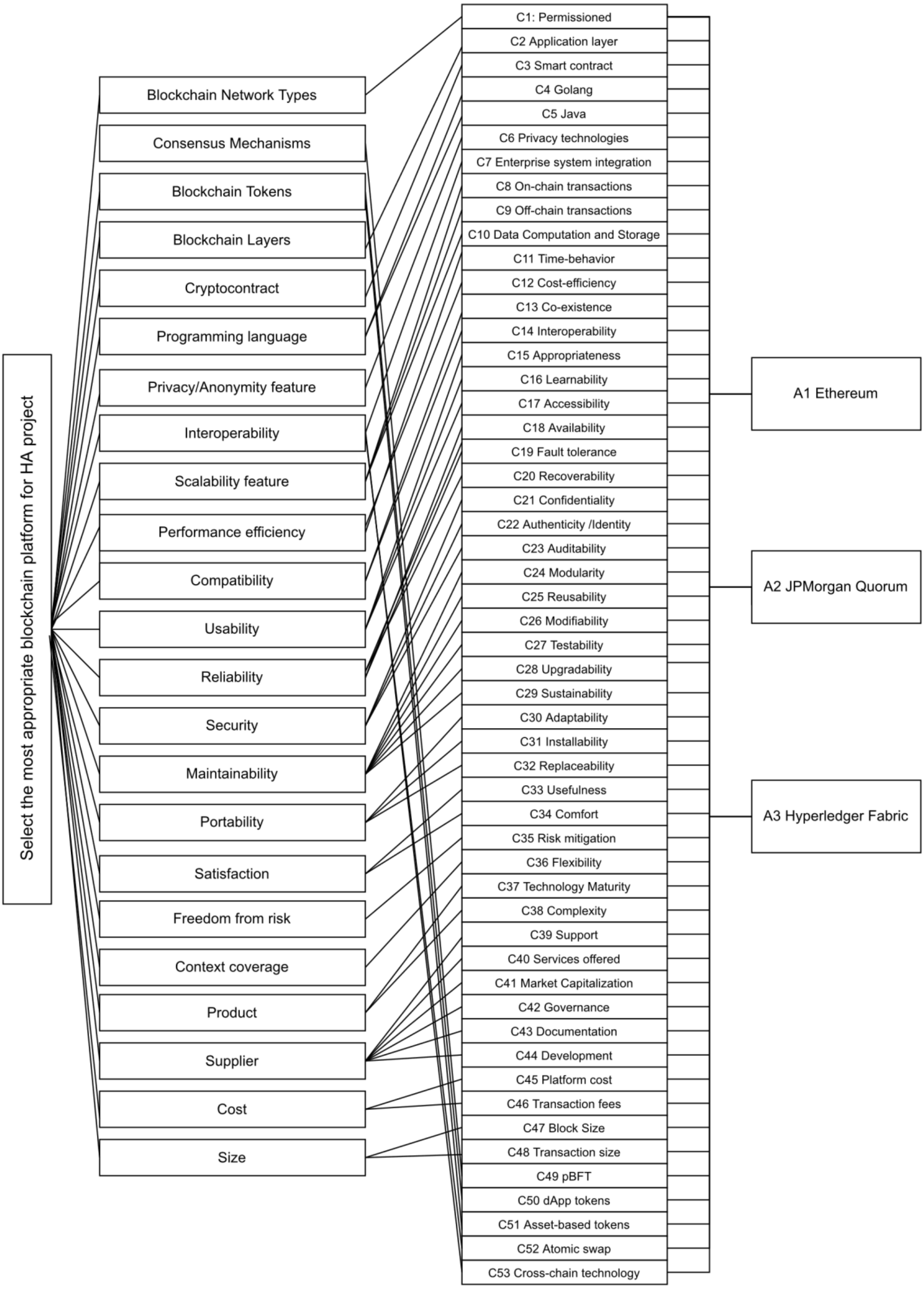

Fig. 3: Evaluation hierarchy system for HA project.

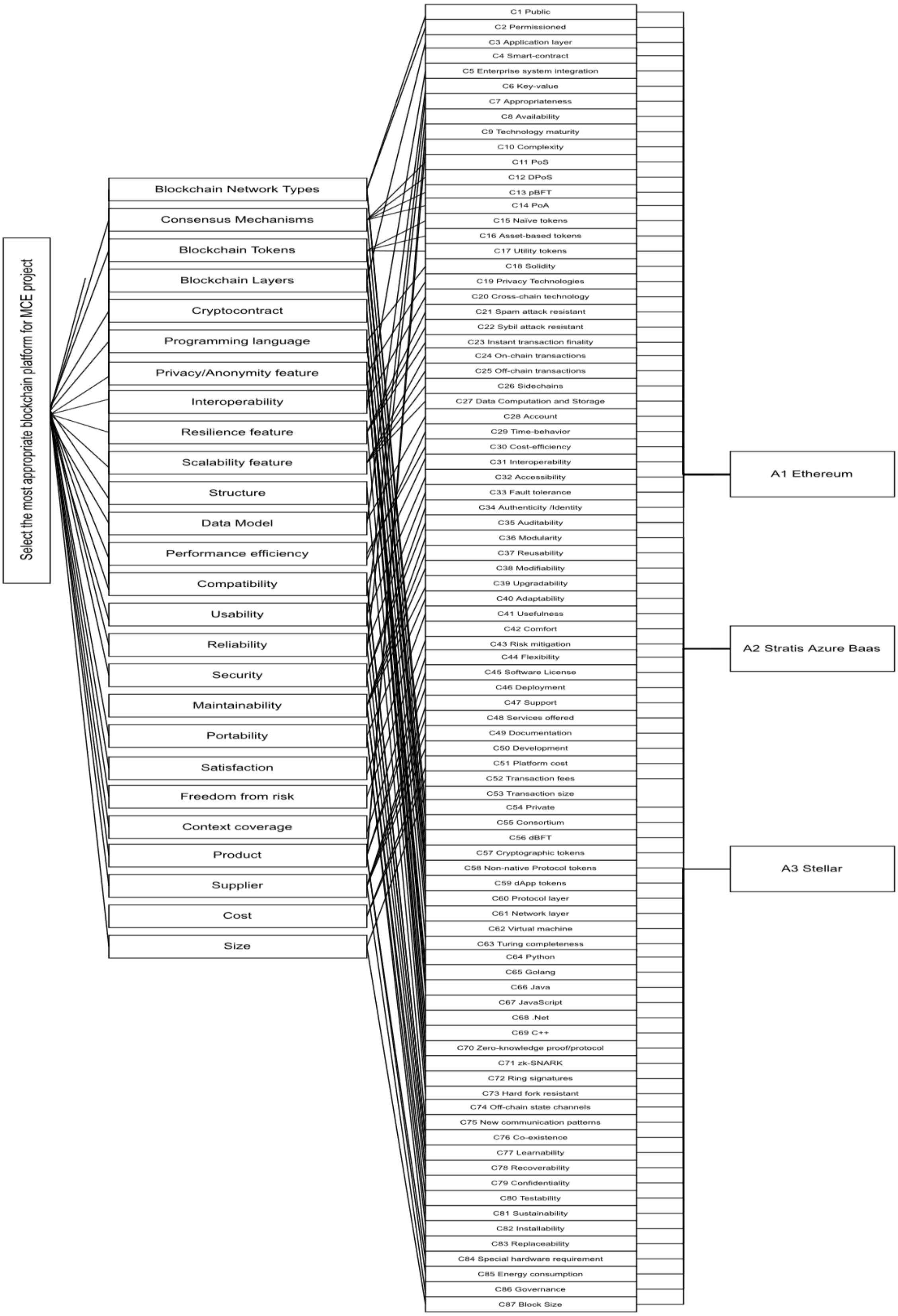

Fig. 4: Evaluation hierarchy system for the MCE project

Table 7: Excerpt of pair-wise comparison matrix for the HA project

	C1	**C2**	**C3**	**…**	**…**	**C51**	**C52**	**C53**
C1	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	…	…	(4.000, 5.000, 6.000)	(4.000, 5.000, 6.000)	(4.000, 5.000, 6.000)
C2	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	…	…	(4.000, 5.000, 6.000)	(4.000, 5.000, 6.000)	(4.000, 5.000, 6.000)
C3	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	…	…	(4.000, 5.000, 6.000)	(4.000, 5.000, 6.000)	(4.000, 5.000, 6.000)
…	**…**	**…**	**…**	**…**	**…**	**…**	**…**	**…**
C51	(0.167, 0.200, 0.250)	(0.167, 0.200, 0.250)	(0.167, 0.200, 0.250)	…	…	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)
C52	(0.167, 0.200, 0.250)	(0.167, 0.200, 0.250)	(0.167, 0.200, 0.250)	…	…	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)
C53	(0.167, 0.200, 0.250)	(0.167, 0.200, 0.250)	(0.167, 0.200, 0.250)	…	…	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)

Table 8: Excerpt of pair-wise comparison matrix for the MCE project

	C1	**C2**	**C3**	**…**	**…**	**C85**	**C86**	**C87**
C1	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	**…**	**…**	(6.000, 7.000, 8.000)	(6.000, 7.000, 8.000)	(6.000, 7.000, 8.000)
C2	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	**…**	**…**	(6.000, 7.000, 8.000)	(6.000, 7.000, 8.000)	(6.000, 7.000, 8.000)
C3	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	**…**	**…**	(6.000, 7.000, 8.000)	(6.000, 7.000, 8.000)	(6.000, 7.000, 8.000)
…	**…**	**…**	**…**	**…**	**…**	**…**	**…**	**…**
C85	(0.125, 0.143, 0.167)	(0.125, 0.143, 0.167)	(0.125, 0.143, 0.167)	**…**	**…**	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)
C86	(0.125, 0.143, 0.167)	(0.125, 0.143, 0.167)	(0.125, 0.143, 0.167)	**…**	**…**	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)
C87	(0.125, 0.143, 0.167)	(0.125, 0.143, 0.167)	(0.125, 0.143, 0.167)	**…**	**…**	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)	(1.000, 1.000, 1.000)

Table 9: Except of fuzzy geometric mean value r_i calculated for HA and MCE projects

Fuzzy geometric mean value	**HA Project**		**Fuzzy geometric mean value**	**MCE Project**
r_1	(1.140, 1.164, 1.184)		r_1	(3.853, 4.740, 5.335)
r_2	(1.140, 1.164, 1.184)		r_2	(3.853, 4.740, 5.335)
r_3	(1.140, 1.164, 1.184)		r_3	(3.853, 4.740, 5.335)
…	**…**	**…**	**…**	**…**
r_{51}	(0.204, 0.233, 0.285)		r_{85}	(0.332, 0.361, 0.410)
r_{52}	(0.204, 0.233, 0.285)		r_{86}	(0.332, 0.361, 0.410)

r_{53}	(0.204, 0.233, 0.285)	r_{87}	(0.332, 0.361, 0.410)

Table 10: Except of fuzzy weights w_i calculated for HA and MCE projects

Fuzzy weight	**HA Project**	**Fuzzy weight**	**MCE Project**
w_1	(1.140, 1.164, 1.184)	w_1	(3.853, 4.740, 5.335)
w_2	(1.140, 1.164, 1.184)	w_2	(3.853, 4.740, 5.335)
w_3	(1.140, 1.164, 1.184)	w_3	(3.853, 4.740, 5.335)
…	…	…	…
…	…	…	…
w_{51}	(0.204, 0.233, 0.285)	w_{85}	(0.332, 0.361, 0.410)
w_{52}	(0.204, 0.233, 0.285)	w_{86}	(0.332, 0.361, 0.410)
w_{53}	(0.204, 0.233, 0.285)	w_{87}	(0.332, 0.361, 0.410)

Table 11: Excerpt of weighted normalized fuzzy decision matrix, FPIS and FNIS values for the HA project

Alternative	**C1**	**C2**	**C3**	**…**	**…**	**C51**	**C52**	**C53**
A1-Ethereum	(0.017, 0.021, 0.021)	(0.017, 0.021, 0.021)	(0.017, 0.021, 0.021)	…	…	(4.000, 5.000, 6.000)	(4.000, 5.000, 6.000)	(4.000, 5.000, 6.000)
A2-JPMorgan Quorum	(0.017, 0.021, 0.021)	(0.017, 0.021, 0.021)	(0.017, 0.021, 0.021)	…	…	(4.000, 5.000, 6.000)	(4.000, 5.000, 6.000)	(4.000, 5.000, 6.000)
A3-Hyperledger Fabric	(0.017, 0.021, 0.021)	(0.017, 0.021, 0.021)	(0.017, 0.021, 0.021)	…	…	(4.000, 5.000, 6.000)	(4.000, 5.000, 6.000)	(4.000, 5.000, 6.000)
FPIS	(0.017, 0.021, 0.021)	(0.017, 0.021, 0.021)	(0.017, 0.021, 0.021)	…	…	(0.003, 0.004, 0.005)	(0.003, 0.004, 0.005)	(0.003, 0.004, 0.005)
FNIS	(0.017, 0.021, 0.021)	(0.017, 0.021, 0.021)	(0.017, 0.021, 0.021)	…	…	(0.000, 0.000, 0.002)	(0.000, 0.000, 0.002)	(0.000, 0.000, 0.002)

Table 12: Excerpt of weighted normalized fuzzy decision matrix, FPIS and FNIS values for the MCE project

Alternative	**C1**	**C2**	**C3**	**…**	**…**	**C85**	**C86**	**C87**
A1-Ethereum	(0.024, 0.038, 0.048)	(0.024, 0.038, 0.048)	(0.024, 0.038, 0.048)	…	…	(0.002, 0.003, 0.004)	(0.001, 0.001, 0.003)	(0.000, 0.000, 0.001)
A2- Stratis Azure Baas	(0.024, 0.038, 0.048)	(0.024, 0.038, 0.048)	(0.024, 0.038, 0.048)	…	…	(0.002, 0.003, 0.004)	(0.002, 0.003, 0.004)	(0.002, 0.003, 0.004)
A3- Stellar	(0.024, 0.038, 0.048)	(0.024, 0.038, 0.048)	(0.024, 0.038, 0.048)	…	…	(0.002, 0.003, 0.004)	(0.002, 0.003, 0.004)	(0.002, 0.003, 0.004)
FPIS	(0.024, 0.038, 0.048)	(0.024, 0.038, 0.048)	(0.024, 0.038, 0.048)	…	…	(0.002, 0.003, 0.004)	(0.002, 0.003, 0.004)	(0.002, 0.003, 0.004)
FNIS	(0.024, 0.038, 0.048)	(0.024, 0.038, 0.048)	(0.024, 0.038, 0.048)	…	…	(0.002, 0.003, 0.004)	(0.001, 0.001, 0.003)	(0.000, 0.000, 0.001)

5.4 Results

Ratings were given to each alternative against the selection criteria. The results of the final ranking generated by the proposed FAT-BPSM for each project are shown in Table 13 and Table 14. As shown in the results, the CC_i value of Hyperledger Fabric (0.822) was much higher than the other two options, Ethereum (0.300) and JPMorgan Quorum (0.298). Hyperledger Fabric was recommended as the most appropriate blockchain platform for the HA project. On the other hand, the CC_i value of Stratis Azure Baas is 0.748 and was ranked number one for the MCE project as compared to Ethereum (0.475) and Stellar (0.420).

Table 13: Blockchain platform alternative ranking for HA project

Alternative	**D^+**	**D^-**	**CC_i**	**Rank**
A1- Ethereum	0.080	0.034	0.300	2
A2- JPMorgan Quorum	0.081	0.034	0.298	3
A3- Hyperledger Fabric	0.020	0.093	0.822	1

Table 14: Blockchain platform alternative ranking for MCE project

Alternative	**D^+**	**D^-**	**CC_i**	**Rank**
A1- Ethereum	0.144	0.131	0.475	2
A2- Stratis Azure Baas	0.072	0.213	0.748	1
A3- Stellar	0.159	0.115	0.420	3

Based on the results presented, both experts evaluated the applicability of the proposed FAT-BPSM by giving feedback through the online discussion session and "Post-evaluation Questionnaire". Table 15 illustrates the ratings on the applicability of FAT-BPSM according to the nine evaluation criteria listed in the questionnaire. Both experts showed strong agreement with the applicability aspects and evaluation process of FAT-BPSM to support the decision-makers in prioritizing requirements, shortlisting selection criteria and selecting the most appropriate blockchain platform based on the requirements. Besides, they also agreed that it is useful to refer to the mapping information (knowledge base) to give ratings to the criteria for each alternative.

Table 15: Ratings given by experts on the applicability of FAT-BPSM

Applicability Criteria	**Expert 1**	**Expert 2**
1. In the FAT-BPSM, by applying Fuzzy AHP, fuzzy weights for each criterion are obtained. These values are then used to rank the alternatives using Fuzzy TOPSIS evaluation. The proposed method supports generating a ranked list of alternatives according to the requirements.	Strongly Agree	Strongly Agree
2. Prioritizing requirements into three group divisions; optional, standard, and critical according to the Numerical Assignment Technique facilitate the requirements specification activity.	Strongly Agree	Strongly Agree
3. Blockchain platforms with the supportability of selected "very important" features are shortlisted as feasible alternatives. This will help to shortlist platforms for better evaluation.	Strongly Agree	Strongly Agree
4. Shortlisted selection features and quality attributes in FAT-BPSM are sufficient to choose a blockchain platform.	Strongly Agree	Agree
5. Shortlisted features match project requirements.	Strongly Agree	Strongly Agree
6. Shortlisted quality attributes match project requirements.	Strongly Agree	Strongly Agree
7. It is useful to refer to the mapping information (knowledge base) to give ratings to criteria for each alternative.	Strongly Agree	Strongly Agree
8. The evaluation process via FAT- BPSM is correct and easy to be understood.	Strongly Agree	Strongly Agree
9. FAT-BPSM will help decision-makers select the most appropriate blockchain platform based on the requirements.	Strongly Agree	Strongly Agree

Some improvements were suggested by the experts for the proposed method. Besides shortlisting the blockchain platforms alternatives based on the very important features, the decision-makers can have the freedom to decide the alternative blockchain platforms that they would like to include for comparison and selection. We have explained to them that shortlisting aims to improve the selection by only including the platforms that have very important (critical) features.

The decision models of the proposed method could be automated based on Decision Model and Notation (DMN) using a web-based tool (e.g., https://bpmn.io/toolkit/dmn-js/). The visualization of decision models can generate blockchain platform recommendations for the projects under consideration. For selection criteria, some decision-makers do not have any technical background and may not know the features of existing blockchain platforms. To support the non-technical decision-makers, characteristics of the business scenarios rather than the technical criteria can be included as selection criteria.

5.5 Discussion

This section discusses the applicability of the proposed method and the limitations identified through the case study.

5.5.1 Applicability

The analysis of the evaluation results in the case study revealed that it is feasible to apply the proposed FAT-BPSM in real projects, as confirmed by both blockchain experts. The proposed method provides a systematic approach to support the whole decision-making process. The case study results show that the proposed method can be applied to prioritize requirements based on three levels (optional, standard, and critical) according to the Numerical Assignment Technique. The very important (critical) features are sufficient to shortlist alternatives of blockchain platforms for the two projects in the case study. Both experts agreed that the shortlisted selection features and quality attributes in FAT-BPSM are adequate to choose a blockchain platform for their projects. The evaluation process via FAT- BPSM is correct and easy to understand.

The improvements suggested by both experts are valuable and will be considered for future work in this research. Based on the feedback from Expert 1, the most recommended platform selected by FAT-BPSM, Hyperledger Fabric was also selected by the team in the HA project. The expert did not disclose this information before the evaluation, and this proves the applicability of FAT-BPSM to generate an accurate ranked list of alternatives according to the project requirements. On the other hand, the MCE project is still in the initial stage and has not selected the blockchain platform that will be adopted in the project. Based on the feedback on applicability, Expert 2 has a strong agreement with the ranked list of recommended platforms chosen by FAT-BPSM. She will show the results of this study and recommend the most appropriate blockchain platform, Stratis Azure Baas to the project team. This demonstrates that FAT-BPSM can be applied to help decision-makers select the most appropriate blockchain platform based on the requirements.

This research presents a comprehensive list of blockchain platforms' features and quality attributes to blockchain practitioners and even to other researchers. While providing decision-makers with a systematic selection method that is accurate and applicable, to select the most appropriate best platform from the possible alternatives by comparing them against a set of evaluation criteria extracted from the concerned project requirements. The most remarkable contributions of this research are the development of a knowledge base (mapping information) that can be used as a reference for rating the possible alternatives and the proposal of a selection method based on integrated MCDM techniques (i.e., Fuzzy AHP-TOPSIS) to select the most appropriate blockchain platform based on project requirements. Both experts applied the knowledge base and strongly agreed that it is useful to assign ratings to criteria for each alternative by referring to the mapping information. The proposed systematic selection process improves the efficiency of the decision-making process and accuracy in selecting the most appropriate blockchain platform.

FAT-BPSM provides a systematic decision-making process to shortlist, compare and rank the alternative blockchain platforms. Fuzzy AHP is used to determine the criteria weights. Then, the weights are adopted in fuzzy TOPSIS to rank alternatives based on user-defined ratings and find out the best alternative for blockchain platform selection problems based on project requirements. This combination has not been yet explored in the blockchain domain. Given the extensive considerations and financial investment in the blockchain platforms, the proposed selection method can be used to ensure the selection of the right platform for blockchain initiatives.

5.5.2 Limitations

The current study was limited by not being specifically designed to consider requirements particular to a specific application domain. Instead, it relies on the requirements provided by decision-makers. Inevitably, there were some discrepancies since blockchain platforms do not use standard terminology for the concepts. Such that, there sometimes different names specify the same concept or terribly the same name introduce distinctive concepts in different blockchain platforms. Further data collection would be needed to address these conflicts to prevent linguistic inconsistency during the selection process. Additionally, the selection criteria may not be suitable for non-technical decision-makers who are more familiar with business use cases or scenarios.

5.6 Threats to validity

Threats to validity were considered when designing the evaluation of the proposed method using a case study. This section discusses the countermeasures taken to mitigate the external, internal and construct threats that may arise when conducting the case study.

To address the external validity threats, two different projects were selected to generalize the findings in the case study. The proposed method, FAT-BPSM, was applied in these two projects that have different requirements to cross-validate the results of the evaluation. Although this case study only includes two projects, the proposed method is generic and applicable in the general context of blockchain-based applications in different domains.

Construct validity concerns the operational measures that are interpreted the same way by researchers and case study participants. Two researchers were involved throughout the case study to assist participants in understanding the proposed method and questionnaires used in this study. An online session was arranged to explain the proposed method and questionnaires to the participants before sending the materials to them. They asked questions during the presentation to clarify their doubts. This is to mitigate the construct validity threats and ensure that both participants have the same understanding of the proposed method and questionnaires used in this study. Both participants were free to give their feedback on the proposed method and case study results without interruptions from the researchers.

The causal relations and design of the case study may affect the internal validity to get the right conclusion for this study. To limit the threats to internal validity, questionnaires and an interview were used as data collection methods. Two researchers conducted the interview together and the interview session was recorded. The data collected using questionnaires and an interview were analysed by both researchers. The selection results of the two projects were analysed by one of the researchers and cross-checked by another researcher. More than one project was used in this case study for evaluation to mitigate the threats to the internal validity of the proposed method.

6.0 CONCLUSION

In this research, firstly, a literature review was conducted to identify important criteria for the comparison and evaluation of blockchains. Existing decision models are analyzed in terms of the multi-criteria decision-making techniques they have used for the comparison and selection of blockchain platforms. Additionally, during the literature review, alternative blockchain platforms, selection criteria, different MCDM techniques and related studies were identified. Based on the literature and identified research gaps, this research proposes a blockchain platform selection method based on Fuzzy AHP-TOPSIS. The FAT-BPSM consists of three main stages (i.e. Pre-selection, Selection stage and Final Stage) to give a systematic evaluation process in comparison and selection of the most appropriate blockchain platform.

To evaluate the proposed selection method, a case study was conducted to demonstrate the applicability of FAT-BPSM for the comparison and blockchain platform selection problem for two projects. The evaluation also shows that the FAT-BPSM can act as a practical and systematic method for supporting the adoption of blockchain technology in blockchain-based applications. The ranked list of alternatives obtained from case studies shows that the methodology works in practical application domains. Despite the limitations of this method, and consequently the evaluation results, the findings are promising to help decision-makers of an organization to compare and select the best-fitted blockchain platform based on their prioritized requirements extracted from the proposed selection criteria.

For future work, a tool can be developed to automate the selection process of FAT-BPSM. Characteristics of the business scenarios can be studied in future research to identify selection criteria for non-technical decision-makers. In addition to that, the scope of the research can be expanded by carrying out a trade-off analysis of the blockchain platform quality attributes to provide decision-makers with a more comprehensive reference for alternative ratings.

ACKNOWLEDGEMENT

This work was supported by the Universiti Malaya Research Grant, RU Geran - Fakulti Program, Grant Number: GPF012D-2019.

APPENDIX: LIST OF BLOCKCHAIN PLATFORMS AND SELECTION CRITERIA

25 open source blockchain platforms have been included in this research as alternatives for comparison and selection are shown as follows:

1. Ethereum
2. R3 Corda
3. JPMorgan Quorum
4. Hyperledger (Fabric)
5. Hyperledger (Sawtooth)
6. BigChainDB
7. MultiChain
8. HydraChain
9. Stratis (Azure Baas)
10. NEO
11. Cardano
12. Stellar
13. Bitshares
14. QTUM
15. Lisk
16. Waves Platform
17. Komodo
18. Bitcoin
19. Zcash
20. Litecoin
21. Dash
22. Peercoin
23. Monero
24. Tendermint
25. EOS

Table 16: Shortlisted features of the blockchain platform included as selection criteria

Type of features	Feature criteria	
Blockchain Network Types	• public blockchain • private blockchain • permissioned	• permissionless • consortium blockchains
Consensus Mechanisms	• Proof-of-work (PoW) • Proof-of-stake (PoS) • Delegated proof of stake (DPoS) • Practical byzantine fault tolerance (pBFT) • Delegated byzantine fault tolerance (dBFT)	• Proof-of-authority (PoA) • Federated byzantine agreement (FBA) • Proof of elapsed time (POET) • SIEVE • Cross-fault tolerance (XFT)
Blockchain Tokens	• Cryptographic tokens • Naïve tokens • Non-native protocol tokens • dApp tokens • Cryptocurrency tokens • Network tokens	• Investment tokens • Asset-based tokens • Network value tokens • Usage tokens • Work tokens • Utility tokens
Blockchain Layers	• Protocol layer • Network layer	• Application layer
Cryptocontract	• Smart contract • Virtual machine	• Turing completeness
Programming language	• Solidity • Python • Golang • Java	• JavaScript • .Net • C++
Privacy/Anonymity feature	• Zero-knowledge proof/protocol • zk-SNARK	• Ring signatures • Privacy technologies
Interoperability	• Atomic swap • Cross-chain technology	• Enterprise system integration
Resilience feature	• Hard fork resistant • Spam attack resistant • Sybil attack resistant	• Quantum attack resistant • Instant transaction finality
Scalability feature	• On-chain transactions • Off-chain transactions • Off-chain state channels • Sidechains	• Sharding • Plasma-chain • Data Computation and Storage
Structure	• Block types (Bitcoin-NG, ComChain) • Parallel block processing	• New communication patterns
Data model	• UTXO	• UTXO+

Type of features	Feature criteria	
	● Account	● Key-value

Table 17: Shortlisted quality attributes and criteria of the blockchain platform included as selection criteria

Quality Attribute	Quality Criteria	
Performance efficiency	● Time-behaviour	● Cost-efficiency
Compatibility	● Co-existence	● Interoperability
Usability	● Appropriateness ● Learnability	● Accessibility
Reliability	● Availability ● Fault tolerance	● Recoverability
Security	● Confidentiality ● Authenticity /Identity	● Auditability
Maintainability	● Modularity ● Reusability ● Modifiability	● Testability ● Upgradability ● Sustainability
Portability	● Adaptability/scalability of internal capacity	● Installability ● Replaceability
Satisfaction	● Usefulness	● Comfort
Freedom from risk	● Risk mitigation	
Context coverage	● Flexibility	
Product	● Guarantees ● Parameterialization ● Software License ● Special Hardware Requirement	● Energy Consumption ● Technology Maturity ● Complexity ● Deployment
Supplier	● Support ● Services offered ● Market Capitalization/Popularity in the market	● Governance (development decisions, etc.) ● Documentation ● Development
Cost	● Platform cost	● Transaction fees
Size	● Block Size	● Transaction size

REFERENCES

[1] M. Staderini, E. Schiavone, and A. Bondavalli, "A requirements-driven methodology for the proper selection and configuration of blockchains", in *IEEE 37th Symposium on Reliable Distributed Systems*, IEEE, 2018, pp. 201-206, https://doi.org/10.1109/SRDS.2018.00031.

[2] K. Wüst, and A. Gervais, "Do you need a blockchain?" in *2018 Crypto Valley Conference on Blockchain Technology*, IEEE, 2018, pp. 45-54, https://doi.org/10.1109/CVCBT.2018.00011.

[3] S. Farshidi, S. Jansen, S. España, and J. Verkleij, "Decision support for blockchain platform selection: Three industry case studies", *IEEE Trans. Eng. Manag.*, Vol. 67 No. 4, 2020, pp. 1109-1128, https://doi.org/10.1109/TEM.2019.2956897.

[4] A. Vacca, A. Di Sorbo, C. A. Visaggio, and G. Canfora, "A systematic literature review of blockchain and smart contract development: Techniques, tools, and open challenges", *J. Syst. Softw.*, Vol. 174, 2021, pp. 110891, https://doi.org/10.1016/j.jss.2020.110891.

[5] P. Frauenthaler, M. Borkowski, and S. Schulte, "A framework for blockchain interoperability and runtime selection", arXiv:1905.07014, Available: *https://doi.org/10.48550/arXiv.1905.07014*, 2019.

[6] O. N. Abdulateef, L. S. Yu, B. N. Abdullateef, and X. P. Zheng, "A Review of Evaluation and Selection of Open-Source Software in Electronic Medical Record", in *2019 International Conference on Informatics, Control and Robotics*, 2019, pp. 460-469.

[7] A. Toloie-Eshlaghy, and M. Homayonfar, "MCDM methodologies and applications: a literature review from 1999 to 2009", *Res. J. Int. Stud.*, Vol. 21, 2011, pp. 86-137.

[8] D. Maček, and D. Alagić, "Comparisons of Bitcoin cryptosystem with other common internet transaction systems by AHP technique", *J. Inf. Organ. Sci.*, Vol. 41 No. 1, 2017, pp. 69-87, https://doi.org/10.31341/jios.41.1.5.

[9] M. Macdonald, L. Liu-Thorrold, and R. Julien, "The blockchain: a comparison of platforms and their uses beyond bitcoin", COMS4507-Advanced Computer and Network Security, Available: *https://doi.org/10.13140/RG.2.2.23274.52164*.

[10] T. T. Anh Dinh, J. Wang, G. Chen, R. Liu, B. C. Ooi, and K. L. Tan, "Blockbench: A framework for analyzing private blockchains", in *Proceedings of the 2017 ACM International Conference on Management of Data*, ACM, 2017, pp. 1085-1100, https://doi.org/10.1016/j.jbi.2014.11.012.

[11] C. Maple, and J. Jackson, "Selecting effective blockchain solutions", in *European Conference on Parallel Processing,* Springer, 2018, pp. 392-403. https://doi.org/10.1007/978-3-030-10549-5_31.

[12] T. T. Kuo, H. Zavaleta Rojas, and L. Ohno-Machado, "Comparison of blockchain platforms: a systematic review and healthcare examples", *J. Am. Med. Inform. Assoc.*, Vol. 26 No. 5, 2019, pp. 462-478, https://doi.org/10.1093/jamia/ocy185.

[13] C. Natoli, J. Yu, V. Gramoli, and P. Esteves-Verissimo, "Deconstructing blockchains: A comprehensive survey on consensus, membership and structure", arXiv:1908.08316, 2019, Available: *https://arxiv.org/abs/1908.08316*.

[14] M. J. M. Chowdhury, M. S. Ferdous, K. Biswas, N. Chowdhury, A. S. M. Kayes, M. Alazab, and P. Watters, "A comparative analysis of distributed ledger technology platforms", *IEEE Access*, Vol. 7, 2019, pp. 167930-167943, https://doi.org/10.1109/ACCESS.2019.2953729.

[15] H. Tang, Y. Shi, and P. Dong, "Public blockchain evaluation using entropy and TOPSIS", *Expert Syst. Appl.*, Vol. 117, 2019, pp. 204-210, https://doi.org/10.1016/j.eswa.2018.09.048.

[16] C. Pahl, N. El Ioini, and S. Helmer, "A decision framework for blockchain platforms for IoT and edge computing", in *Proceedings of the 3rd International Conference on Internet of Things, Big Data and Security*, SciTePress, 2018, pp. 105–113, https://doi.org/10.5220/0006688601050113.

[17] M. Belotti, N. Božić, G. Pujolle, and S. A. Secci, "Vademecum on Blockchain Technologies: When, Which, and How", *IEEE Commun. Surv. Tutor.*, Vol. 21 No. 4, 2019, pp. 3796-3838, https://doi.org/10.1109/COMST.2019.2928178.

[18] T. Koens, and E. Poll, "What blockchain alternative do you need?", in *Data Privacy Management, Cryptocurrencies and Blockchain Technology*, Springer, 2018, pp. 113-129, https://doi.org/10.1007/978-3-030-00305-0_9.

[19] A. A. Zaidan, B. B. Zaidan, A. Al-Haiqi, M. L. M. Kiah, M Hussain, and M. Abdulnabi, "Evaluation and selection of open-source EMR software packages based on integrated AHP and TOPSIS", *J. Biomed. Inform.*, Vol. 53, 2015, pp. 390-404, https://doi.org/10.1016/j.jbi.2014.11.012.

[20] E. Triantaphyllou, and S. H. Mann, "An examination of the effectiveness of multi-dimensional decision-making methods: A decision-making paradox", *Decis. Support Syst.*, Vol. 5 No. 3, 1989, pp. 303-312, https://doi.org/10.1016/0167-9236(89)90037-7.

[21] A.S. Jadhav, and R. Sonar, "Evaluating and selecting software packages: A review", *Inf. Softw. Technol.*, Vol. 51, 2009, pp. 555-563, https://doi.org/10.1016/j.infsof.2008.09.003.

[22] M. Velasquez, and P. T. Hester, "An analysis of multi-criteria decision making methods", *Int. J. Oper. Res.*, Vol. 10 No. 2, 2013, pp. 56-66.

[23] K. Kabassi, A. Botonis, and C. Karydis, “Evaluating Websites of Specialized Cultural Content Using Fuzzy MultiCriteria Decision Making Theories”, *Informatica*, Vol. 44 No. 1, 2020, pp. 45-54, https://doi.org/10.31449/inf.v44i1.2689.

[24] P. Minetola, L. Iuliano, and F. Calignano, “A customer-oriented methodology for reverse engineering software selection in the computer aided inspection scenario”, *Comput. Ind.*, Vol. 67, 2015, pp. 54-71, https://doi.org/10.1016/j.compind.2014.11.002.

[25] G. Secundo, D. Magarielli, E. Esposito, and G. Passiante, “Supporting decision-making in service supplier selection using a hybrid fuzzy extended AHP approach”, *Bus. Process Manag. J.*, Vol. 23 No. 1, 2017, pp. 196-222, https://doi.org/10.1108/BPMJ-01-2016-0013.

[26] M. A. Serhani, H. A. Kassabi, and I. Taleb, “Towards an efficient federated cloud service selection to support workflow big data requirements”, *Adv. Sci. Technol. Eng. Syst. J.*, Vol. 3 No. 5, 2018, pp. 235-247, https://doi.org/10.25046/aj030529.

[27] M. Sharma, R. Gupta, and P. Acharya, “Prioritizing the critical factors of cloud computing adoption using multi-criteria decision-making techniques”, *Glob. Bus. Rev.*, Vol. 21 No. 1, 2020, pp. 142-161, https://doi.org/10.1177/0972150917741187.

[28] L. Sun, H. Dong, F. K. Hussain, O. K. Hussain, J. Ma, and Y. Zhang, “A hybrid fuzzy framework for cloud service selection”, in *2014 IEEE International Conference on Web Services*, IEEE, 2014, pp. 313-320. https://doi.org/10.1109/ICWS.2014.53.

[29] L. Sun, J. Ma, Y. Zhang, H. Dong, and F. K. Hussain, “Cloud-FuSeR: Fuzzy ontology and MCDM based cloud service selection”, *Future Gener. Comput. Syst.*, Vol. 57, 2016, pp. 42-55, https://doi.org/10.1016/j.future.2015.11.025.

[30] A. Hudaib, R. Masadeh, M. H. Qasem, and A. Alzaqebah, “Requirements prioritization techniques comparison”, *Mod. Appl. Sci.*, Vol. 12 No. 2, 2018, pp. 62, https://doi.org/10.5539/mas.v12n2p62.

[31] Q. Ma, *The effectiveness of requirements prioritization techniques for a medium to large number of requirements: a systematic literature review*. Doctoral dissertation, Auckland University of Technology, https://openrepository.aut.ac.nz/handle/10292/833, 2009.

[32] C. C. Sun, “A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods”, *Expert Syst. Appl.*, Vol. 37 No. 12, 2010, pp. 7745-7754, https://doi.org/10.1016/j.eswa.2010.04.066.

[33] S. Vinodh, M. Prasanna, N. H. Prakash, “Integrated Fuzzy AHP–TOPSIS for selecting the best plastic recycling method: A case study”, *Appl. Math. Model.*, Vol. 38 Issues 19-20, 2014, pp. 4662-4672, https://doi.org/10.1016/j.apm.2014.03.007.

[34] T. L. Saaty, “Decision making with the analytic hierarchy process”, *Int. J. Serv. Sci.*, Vol. 1 No. 1, 2008, pp. 83-98.

[35] P. Sirisawat, and T. Kiatcharoenpol, “Fuzzy AHP-TOPSIS approaches to prioritizing solutions for reverse logistics barriers”, *Comput. Ind. Eng.*, Vol. 117, 2018, pp. 303-318, https://doi.org/10.1016/j.cie.2018.01.015.

[36] M. S. F. Soberi, and R. Ahmad, “Application of fuzzy AHP for setup reduction in manufacturing industry”, *J. Eng. Res. Educ.*, Vol. 8, 2016, pp. 73-84.

[37] J. J. Buckley, “Fuzzy hierarchical analysis”, *Fuzzy sets and systems*, Vol. 17 No. 3, 1985, pp. 233-247, https://doi.org/10.1016/0165-0114(85)90090-9.

[38] S. Nădăban, S. Dzitac, and I. Dzitac, “Fuzzy topsis: A general view”, *Procedia Comput. Sci.*, Vol. 91, 2016, pp. 823-831, https://doi.org/10.1016/j.procs.2016.07.088.

[39] P. Runeson, and M. Höst, “Guidelines for conducting and reporting case study research in software engineering”, *Empir. Softw. Eng.*, Vol. 14 No. 2, 2009, pp. 131-164, https://doi.org/10.1007/s10664-008-9102-8.

[40] A. Sasikumar, B. Karthikeyan, S. Arunkumar, P. Saravanan, V. Subramaniyaswamy, and L. Ravi, L, “ Blokchain-based Decentralized user authentication scheme for letter of guarantee in financial contract management”, *Malaysian Journal of Computer Science*, 31 March 2022, pp. 62-73, https://doi.org/10.22452/mjcs.sp2022no1.5.

[41] R. Jayaraman, V. Subramaniyaswamy, and L. Ravi, “An adaptive hesitant fuzzy sets based group recommendation system”, *Malaysian Journal of Computer Science*, 26 November 2020, pp. 124-139, https://doi.org/10.22452/mjcs.sp2020no1.9.