SYSTEMATIC SELECTION OF BLOCKCHAIN PLATFORMS USING FUZZY AHP-TOPSIS

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SYSTEMATIC SELECTION OF BLOCKCHAIN PLATFORMS USING FUZZY AHP-TOPSIS

ABSTRACT

Various businesses and industries such as financial, medical care management, supply chain management, systematic instruction, data management, fundraising platforms, Internet of Things (IoT) and government supremacy, have been using blockchain technology to develop systems. Similar to other technologies, despite the superiority it holds, some shortcomings and issues accompany the adoption of Blockchain. interoperability challenges, security attacks, sustainability, latency, availability issues related to blockchain performance and scalability are listed as the most critical challenges standing against its vast adoption. If the blockchain platform is not properly selected, the functionality and quality of the blockchain-based systems could be biased. Furthermore, choosing the right platform that best meets the project requirements and targets is getting complicated due to the availability of numerous blockchain platforms with unique properties and specifications. For this, the design of a systematic selection method that contributes decision-makers toward a suitable blockchain platform choice is highly desirable. During the selection of blockchain platforms, many criteria need to be taken into account depending on the organization, project and use case requirements. If the selection criteria are derived carefully concerning the specified factors, the effectiveness and feasibility of the selection method will be enhanced. This research proposes a set of selection criteria that cover both features and quality attributes of the blockchain platforms. A systematic selection method is proposed based on the Fuzzy AHP-TOPSIS approach which compares and select alternative blockchain platforms against the selection criteria. Three industrial cases were used to prove the accuracy of the ranked list of alternatives generated by the proposed selection method. Additionally, an evaluation by blockchain experts was performed and the results show that the proposed selection method can be applied practically to support the decision-makers in blockchain platform selection for real-world projects.

Keywords: blockchain, blockchain platforms, multicriteria decision-making methods, selection method, Fuzzy AHP-TOPSIS

PEMILIHAN SISTEMATIK PLATFORM BLOCK RANTAI DENGAN MENGGUNAKAN FUZZY AHP-TOPSIS

ABSTRAK

Pelbagai perniagaan dan industri seperti kewangan, pengurusan rawatan perubatan, pengurusan rantaian bekalan, arahan sistematik, pengurusan data, platform penggalangan dana, *Internet of Things (IoT)* dan ketuanan pemerintah, telah menggunakan teknologi blockchain untuk mengembangkan sistem. Sama seperti teknologi lain, di sebalik keunggulannya, beberapa kekurangan dan masalah mengenai penggunaan block rantai. cabaran interoperabiliti, serangan keselamatan, kesinambungan, kependaman, masalah ketersediaan yang berkaitan dengan prestasi blok rantai dan skalabiliti disenaraikan sebagai cabaran yang paling kritikal yang dikenal pasti menentang penerapannya yang luas. Sekiranya platform blok rantai tidak dipilih dengan betul, fungsi dan kualiti sistem berasaskan blok rantai mungkin berat sebelah. Selanjutnya, memilih platform yang tepat yang memenuhi kehendak dan sasaran projek menjadi semakin rumit kerana terdapat banyak platform blok rantai dengan sifat dan spesifikasi yang unik. Untuk ini, reka bentuk kaedah pemilihan sistematik yang menyumbang kepada pembuat keputusan ke arah pilihan platform blok rantai yang sesuai sangat diinginkan. Semasa pemilihan platform blok rantai, banyak kriteria perlu dipertimbangkan bergantung pada organisasi, projek dan keperluan kes penggunaan. Sekiranya kriteria pemilihan diperolehi dengan teliti mengenai faktor-faktor yang ditentukan, keberkesanan dan kelayakan kaedah pemilihan akan ditingkatkan. Penyelidikan ini mencadangkan satu set kriteria pemilihan yang merangkumi kedua-dua ciri dan atribut kualiti platform blok rantai. Kaedah pemilihan sistematik dicadangkan berdasarkan pendekatan *Fuzzy AHP-TOPSIS* yang membandingkan dan memilih platform blok rantai alternatif dengan kriteria pemilihan. Tiga kes industri digunakan untuk membuktikan ketepatan senarai kedudukan alternatif yang dihasilkan oleh kaedah pemilihan yang dicadangkan. Selain itu, penilaian oleh pakar blok rantai dilakukan dan hasilnya menunjukkan bahawa kaedah pemilihan yang dicadangkan dapat diterapkan secara praktikal untuk menyokong para pembuat keputusan dalam pemilihan platform blok rantai untuk projek dunia sebenar.

Kata Kunci: blok rantai, block rantai platform, kaedah membuat keputusan multikriteria, kaedah pemilihan, *Fuzzy AHP-TOPSIS*

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LIST OF SYMBOLS AND ABBREVIATIONS

AHP	:	Analytic Hierarchy Process
TOPSIS	:	Technique for Order Preferences by Similarity to Ideal Solutions
MCDM	:	Multiple-criteria decision-making
DLT	:	Distributed Ledger Technology
DM	:	Decision matrix
WSM	:	Weighted sum model
BDT	:	Boolean Decision Tree
DSS	:	Decision Support System
FAT-BPSM	:	Fuzzy AHP-TOPSIS Blockchain Platform Selection Method
FPIS	:	Fuzzy Positive Ideal Solution
FNIS	:	Fuzzy Negative Ideal Solution

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CHAPTER 1: INTRODUCTION

1.1 Background

One of the most evolving technologies in recent times is the blockchain network (Chowdhury et al., 2019; Casino et al., 2019) which assist the progress of decentralized infrastructures. Members of the blockchain network can make consensus on the way they share their data or make payments over an unreliable network of participants without the need for a trusted intermediary (Xu et al., 2017; Wieninger et al., 2019). Numerous domains such as IoT, big data, cloud and edge computing, identity management, cryptocurrency, economics and markets, business solutions, automation, supply chains, healthcare records and communication are starting to make use of this new technology (Gao et al., 2018; Xu et al., 2016; Belotti et al., 2019; Beller & Hejderup, 2019; Casino et al., 2019).

A blockchain architecture consists of various types of layers (Xu et al., 2016; Belotti et al., 2019; Eyal, 2017; Gao et al., 2018; Farshidi et al., 2020; Anh Dinh et al., 2017) and each layer has different applications and platforms. The three main layers are the data layer, blockchain layer, middleware layer and the application layer. The data layer is the data storage system layer that stores data. The blockchain layer is the distributed ledger layer where all the transactions are being recorded. Middleware, also known as the development layer, comprises any services or functions that have been developed based on blockchain products. The application layer is the layer where applications such as Facebook and Google run on.

Owing to the growing receptiveness of blockchain technology, numerous platforms have been developed to support each layer of blockchain-based systems. Nonetheless, in advance of selecting the best fitting blockchain platform for designing and development of blockchain-based systems, many criteria, for instance, ledger type (i.e., permissionless, permissioned, public, private), consensus algorithm (e.g., Proof of Work, Proof of Stake, Proof of Burn), fees, smart contract functionality, security and privacy, interoperability, and scalability need to be taken into consideration (Farshidi et al., 2020).

Blockchain platforms give the thumbs up to blockchain-based applications development. There are different types of blockchain platforms such as permissioned or permissionless, private and public (Farshidi et al., 2020). Ethereum, Hyperledger, R3, Ripple and EOS are some examples attributable to providing people with the framework for developing and hosting their applications on the blockchain.

To better determine which blockchain platform suits a particular context, many decision models have been introduced. Bearing in mind, that these models are different for their proposed methodologies. Meanwhile, distinctive frameworks can come up with different solutions for similar decision problems (Koens & Poll, 2018). The process of decision-making for selecting blockchain platforms is even more tangled because all platforms do not offer equal services with equivalent performance qualifications (Belotti et al., 2019; Chowdhury et al., 2019).

Multiple-criteria decision-making (MCDM) has the advantage to facilitate the process of evaluation resulting in an accelerated and accurate decision. In this context, the MCDM problem can be considered part of the selection method between the different blockchain platform alternatives based on several criteria. MCDM provide decision-makers with the support to choose the best alternative, identify potential alternatives between options, and rank alternatives in descending order based on their performance (Abdulateef et al., 2019). This research attempts to propose a systematic decision model based on the Fuzzy AHP-TOPSIS method to solve the problem of blockchain platform selection.

1.2 Problem Statements

Technology constantly continues to evolve with drawing attention to even more voluminous developments unstoppably. Developers, scientists, entrepreneurs, and government are strikingly pushing the boundaries of technology to higher peaks taking no rest. As of now, Blockchain has gained popularity owing to providing a reliable distributed architecture (Staderini et al., 2018; Wüst & Gervais, 2018) for any sort of business occurrences. Growingly, various high-tech manufacturing companies have become mindful of blockchain network applications in their software products (Farshidi et al., 2020).

To select the most appropriate blockchain platform, multiple criteria such as functionality, amenability, and interoperability of the platform to the current software product, etc. need to be assessed. The decision-making process is a difficult task since software developers are not skillful in every discipline. With an increment in the number of decision-makers, alternatives and criteria, analysis becomes perplexing and would be difficult to decide on the best blockchain platform. Consequently, the need for a decision model for blockchain platform selection is realized (Farshidi et al., 2020).

Choosing the most fitting blockchain platform is considered a challenging selection process because it involves complex, multi-criterion problems (Frauenthaler et al., 2019) whose objectives may sometimes conflict. Furthermore, the excessive amount of information with conflicting objectives in a multi-attribute problem is beyond the capability of the human's brain (Abdulateef et al., 2019) and needs a sufficient selection process. In most of the studies related to blockchain platform selection, only one type of selection criteria, either functional (features) or non-functional criteria (quality attributes) is considered when proposing the new selection method. However, selection of the most fitting blockchain platform to meet specified project requirements involves consideration and comparison of a large number of both features and quality attributes against different blockchain alternatives, thereby blockchain platform selection is a multi-criteria decision-making problem with the provision that it has a critical role in the competitiveness of software producing organizations.

According to Toloie-Eshlaghy and Homayonfar (2011), "multiple criteria decisions making (MCDM) is an important part of modern decision science," (p. 86) that provides decision-makers with the ability to meet variegated decision criteria and multitudinous alternatives problems. Although the MCDM approaches offer a solution to numerous real-life problem which involves several criteria analysis, the motivation behind their rising implementation is the longing of experts to utilize the up-to-date mathematical optimization enhancements, scientific computation, and computer technology in their envisioned decision-making approaches (Toloie-Eshlaghy & Homayonfar, 2011). There are numerous studies on blockchain comparison frameworks based on benchmarking experiments, but the suggested frameworks are not subject to a rigid mathematical foundation like AHP, TOPSIS (Maček & Alagić, 2017) or some other MCDM techniques.

Many different MCDM methods have been forged and put to good use in the decision-making process at different application domains such as cloud service selection, service supplier and software evaluation over the past few decades. Every technique has some strengths and some shortcomings. To address one method's deficiencies, multiple methods may be combined (Velasquez & Hester, 2013). Moreover, a single MCDM technique is not always sufficient to provide the best decision, alternative ranking or weight calculations are often the difficulties most techniques have in either way. Therefore, there is a need to apply the integrated approach to deal with these problems (Triantaphyllou, 2000). A few studies have used single MCDM technique like AHP and TOPSIS in their proposed approaches for the blockchain platform selection problem, but none of them used a combination of MCDM techniques. To address the aforementioned problem, this research will propose a systematic selection method of blockchain platforms based on an integration of three MCDM approaches, Fuzzy AHP-TOPSIS to overcome the limitations of one technique with the other.

1.3 Research Questions

1. What are the types, features and quality attributes of the existing blockchain platforms?
2. What criteria are useful to compare and select appropriate blockchain platforms for specific project needs?
3. How can blockchain platforms be compared to select the most appropriate platform based on multi-criteria decision-making (MCDM) techniques?
4. How can the proposed method be evaluated?

1.4 Research Objectives

The objective of this study is to design a systematic selection method on the application of MCDM methods in the decision process related to the blockchain platform selection. The following points are considered as objectives of this paper:

1. To investigate existing blockchain platforms' features and quality attributes
2. To identify selection criteria (features and quality attributes) that impacts the comparison and selection of all types of blockchain platforms.
3. To develop a method based on an integrated MCDM technique, Fuzzy AHP-TOPSIS to overcome the limitations of one MCDM technique with another and meet specific project needs.
4. To evaluate the accuracy and applicability of the proposed selection method.

1.5 Scope

This study focuses on the selection of open source Blockchain platforms of any type (i.e., permissionless, permissioned, public, private) and proposes a selection method intended to support decision-makers who do not have in-depth knowledge of blockchain to select appropriate blockchain platforms for their projects and software products. Open-source platforms are convenient for adoption and innovation because everyone can download and/or modify a platform (Macdonald et al., 2017). The proposed selection method considers several features and non-functional criteria quality attributes as selection criteria to evaluate and compare different blockchain platforms and rank them based on their importance. The Fuzzy AHP-TOPSIS integrated approach was used to solve the multi-criteria decision-making problem of blockchain platform selection. The proposed Fuzzy AHP-TOPSIS Blockchain Platform Selection Method (FAT-BPSM) was evaluated by conducting three case studies and the applicability check by two blockchain experts.

1.6 Significance of Research

This research identified significant evaluation criteria (i.e., features, quality attributes) that can be considered during the selection of blockchain platforms for different types of projects, applications and use cases. The identified evaluation criteria can help other researchers, blockchain practitioners and decision-makers in the selection of blockchain platforms based on their project requirements. The proposed selection method addresses the complexity and problems of selecting appropriate blockchain platforms with a systematic approach and provides a step-by-step guideline to support the evaluation and decision-making process. Moreover, this study addresses the need for the updated and validated version of the mapping information which is useful and valuable in shortlisting a list of possible blockchain alternatives for comparison.

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. Most importantly, this combination has not yet been applied in the blockchain platform selection. A Fuzzy AHP-TOPSIS integrated approach contributes to overcoming the difficulties of one MCDM technique with another technique while speeding up the assessment process and dealing with the uncertainty of human judgements during comparison.

1.7 Thesis outline

The content of this research contains the following:

Chapter 1, The **Introduction** chapter gives an overview of the study conducted. Subsections under this chapter, such as problem statements, research questions, objectives, and significance of the research, will provide readers, a complete understanding of this study.

Chapter 2, The **Literature Review** chapter presents the background related to this study. The content of this chapter includes an overview of Blockchain and DLT, benefits or advantages of blockchains, challenges and limitations of Blockchain, existing Blockchain implementations, Blockchain adoption, MCDM literature analysis and comparison and related studies of blockchain platform selection and their analysis for the designing selection method.

Chapter 3, The **Research Methodology** chapter, demonstrates precisely the entire methodology applied in this study. Each step of the applied methodology is discussed in detail.

Chapter 4, The **Proposed Work** chapter will present a precise explanation of the proposed selection method for the blockchain platform selection problem.

Chapter 5, The **Evaluation** chapter explains the evaluations conducted to evaluate the selection criteria, alternative blockchain platforms and proposed work.

Chapter 6, The **Conclusion** chapter summarizes the research and discusses the contributions of the study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter comprises the comprehensive background of the research topic and discusses the previous related work. It begins with the introduction to blockchain and Distributed Ledger Technology (DLT) and discusses underlying concepts of blockchain and relevant techniques, highlights its critical features, advantages, challenges, and limitations (Section 2.2). Section 2.3 discusses some of the existing blockchain-based platforms or applications. Section 2.4 explains how blockchain can be applied or adopted in a software system. Section 2.5 discusses MCDM techniques and provides an analysis of MCDM techniques applied in existing studies. Section 2.6 discusses related studies of blockchain platform selection and provides a comparison of related studies based on evaluation criteria and alternatives (blockchain platforms). Besides, it will present the research gaps identified in the related studies (Section 2.7). Lastly, a summary is presented in Section 2.8.

2.2 Blockchain and DLT

In this section, a brief introduction to Blockchain and Distributed Ledger Technology (DLT) and underlying concepts of blockchain and relevant techniques is presented in subsection 2.2.1. Benefits and advantages of Blockchain are highlighted in subsection 2.2.2 and in subsection 2.3.3 some of the challenges and limitations of Blockchain are discussed.

2.2.1 Overview of Blockchain and DLT

According to El Ioini and Pahl (2018), DLT which is an acronym for Distributed Ledger Technologies is defined as data structures designed to store transactions with the possibility to change based on general agreements. Different types of DLTs are developed over time for example Blockchain, Tangle, Hashgraph, and Sidechain. Each presents a distinguished data model and technology. The commonalities between all DLTs are 1) digital signature to ensure trust and security 2) peer-to-peer distributed connecting nodes to improve scalability 3) agreements mechanism to avoid centralization.

Chowdhury et al. (2019) explained that for some periods, blockchain and DLT were used as synonyms, although the term DLT is more general and presents different types of ledgers, each of which stores data in a different format. Blockchain is a popular form of distributed ledger (El Ioini & Pahl, 2018; Chowdhury et al., 2019; Maple & Jackson, 2018). Blockchain technologies can be distinguished from DLTs based on the way they store information. Blockchain is considered as an append-only architecture; a justification for this is that it allows only new augmentation or addition to the existing data Maple & Jackson (2018). This revolutionary technology benefits from a peer-to-peer system distributed within a network using a decentralized manner. Several properties related to data integrity are ensured by the consensus algorithm agreed by all participating components.

Blockchain adoption has been rising due to the properties that it inherited from DLT, such as resiliency, integrity, anonymity, decentralization, and autonomous control. From application domains that began to use blockchain rapidly as their infrastructure, we can point to accounting, auditing, healthcare, education, supply chain, transportation, and governance (Chowdhury et al., 2019).

As the name suggests, blockchain is a chain of blocks in order. Each block has two parts, the first part is the transactions in the case of cryptocurrency or any kind of data. and the second part is a hash of the former block. This way of storing information enables the inalterability of data in an untrusted setting (Xu et al., 2017). Although transactions can be reversible or changeable if most blockchain participants reach an agreement to do so (Wang & Kogan, 2018). Lots of research have been done to study this database solution from different perspectives. According to Xu et al. (2016), "Considering the blockchain as a software connector helps make explicitly important architectural considerations on the resulting performance and quality attributes (for example, security, privacy, scalability and sustainability) of the system".

2.2.2 Benefits of Blockchains

It is no surprise that this storage technology comes with some underlying attributes. According to Xu et al. (2017), "These properties are data immutability, integrity, equality of users, transparency, and a distributed consensus that guarantees nonrepudiation of transactions." The reason that this storage technology has been implemented in many application domains increasingly is the prospects and possibilities it comes with. Content tamper resistance, mining profits, transparency, commercial usage, and the growing number of implementations are some of the characteristics and advantages of blockchain stated by El Ioini and Pahl (2018).

The most significant aspect of participating in a Blockchain network is the use of a private key which makes it more secure in comparison with the other technologies, although it is not completely guaranteed. Any unauthorized and dishonest access to blockchain is banned and users have full control over their information (Kshetri, 2018). Transparency which results from documentation of any small changes in the transactions comes in form of audit trails, considered to be listed as an advantage by many researchers (Xu et al., 2017; El Ioini & Pahl, 2018; Kshetri, 2018; Gao et al., 2018).

A similar study was done by Gao et al. (2018) assessing blockchain from a high-level framework perspective, pointing out fault tolerance, attack resistance and transparency as novel characteristics of a blockchain model. He explained that blockchain-based systems can handle one defect in many components typically, provided that the total number of errors does not proceed to half of all the participating nodes. Any kind of modification to electronic records is quite hard or nearly impossible because it needs the agreement of most nodes. Blocks are added to blockchain only if they can perform the mathematical operations successfully. Also, transactions are added based on their time being generated which solves the double-spending problem. Every transaction change detail is audited in the platform (Gao et al., 2018).

2.2.3 Challenges and Limitations of Blockchain

Despite all the virtues this technology possesses, there are some shortcomings. Permission-less public blockchains have data privacy and scalability issues. Everyone can access the public blockchain and confirm other transactions. Data Storage limitation, Latency between submission and validation, a limited number of transactions that can include in a block are examples of the disadvantage of using blockchain platforms as mentioned by Xu et al. (2017).

Although Kshetri (2018) believed that a lack of knowledge about blockchain's potentials is a bigger obstacle to the path of introducing blockchain in comparison to technical barriers. Adoption of the technology in the medical field might face other hurdles as well. Scalability is a common challenge across all blockchain implementations in diverse settings. As patients' medical records increase frequently, storing the exact copy of the information in every participating node, causes data-storage and bandwidth challenges. When it comes to control and ownership, the inability of older persons and mental patients to handle their medical status in a blockchain network and psychological effects are other challenges that healthcare providers need to address.

In the same light, Wang and Kogan (2018) explored the challenges of blockchain adoption. Their review process highlighted confidentiality as a concern that business companies must deal with when using blockchain. However, fewer data confidentiality results in increased reliability of the blockchain network as the number of participating nodes increases.

Xu et al. (2016) described Scalability, data privacy and cost as considerable criticisms that public blockchain platforms would relate to. They compared the average of transactions per second that could be handled by Bitcoin and Ethereum against other financial services such as Visa as an example to illustrate public blockchain scalability issues. Besides, publicly accessible information could risk data privacy and running computations on the blockchain needs to spend money.

El Ioini and Pahl (2018) argued that the most remarkable problem of using blockchain as the infrastructure is their performance. He explained that most blockchains' performance is affected generally while they try to resolve security defects by affiliating the mechanism of Proof of Work. He also mentioned that the performance of a blockchain-based system is dependent on several attributes, such as how many transactions can be processed in a second (tps), how many transactions make up one block and how long it takes to validate the electronic records. Lack of interoperability, low scalability and transaction fees is also considered as disadvantages of this technology based on SWOT analysis done by El Ioini and Pahl.

Research by Gao et al. (2018) supports that the two main obstacles of adopting blockchain platforms are performance and security. The author branched majority attacks and selfish mining, anonymity, and abuse of blockchain as security issues. As mentioned before, the blockchain model provides data storage between untrusted participants. The data cannot be altered after a consensus mechanism is applied and the block is verified in the chain. Although the mechanism could be an aim for malicious attacks. Privacy disclosure happens when all electronic records are available publicly. Furthermore, sometimes the immutability of data in the public ledger causes the persistence of unauthorized blocks forever. Nonetheless, strategies must be taken to enhance the performance of the model (Gao et al., 2018).

Research by Casino et al. (2019) revealed energy waste due to mining also counts as a disadvantage of this growing technology. Chinese Bitcoin leading miners use electricity more in comparison to 159 other countries (Digiconomist, 2017). Malware infections can cause mining unintentionally which increases energy consumption. To solve the power consumption problem, experts suggest using efficient cryptocurrency and bitcoin consensus mechanisms.

2.3 Blockchain platforms

El Ioini and Pahl (2018) classify blockchain platforms into three categories: permissioned, permissionless and private. Permissioned blockchain platforms can be accessed by known users within several organizations while it is controlled to an extent. Although everyone can join a permissionless public blockchain and add new transactions and blocks. Bitcoin and Ethereum are two well-known examples of these platforms. Apparently, full control is enforced on private blockchains that are generally run by one foundation (El Ioini & Pahl, 2018).

Blockchain technology has drawn the attention of a lot of investors, which caused the rapid growth of this emerging model. Implementation and deployment have been eased with introducing blockchain-as-a-service platforms such as Azure 3 and development frameworks like BlockApp4. The first generation of blockchain-based applications was introduced by the cryptocurrency system, Bitcoin. Smart contracts are considered the second generation. This is because they enabled users with complicated programmable transactions. Blockchain participants can use smart contracts to reach agreements and perform complex computations. Ethereum is another example that benefits from a built-in Turing-complete script language named Solidity, to have their customized version of the model (Xu et al., 2017).

Blockchain-based application development has affected a vast number of industries and areas including IoT, big data, cloud and edge computing, identity management, cryptocurrency, economics and markets, business solutions, automation, supply chains, healthcare records, communication, and others. Because of removing the need for a central authority and capabilities blockchain offers and as there is a diverse range of platforms to implement blockchain, researchers are working hard to address applications in the mentioned spheres (Gao et al., 2018).

Bitcoin, Peercoin, Colouredcoins, Omni and Nxt are some examples of the most common and reputed cryptocurrency platforms which use blockchain as their infrastructure. For Smart contract platforms; Etheruem and Counterparty and for Ledger platforms; Factom, Ripple, Eris, MultiChain and Enigma are named widely (Xu et al., 2016).

Wang and Kogan (2018) proposed a prototype named Bb-TPS (Blockchain-based transaction processing system) to serve real-time accounting functionalities practically as well as adopting zero-knowledge proof mechanism and homomorphic encryption to prevail over the confidentiality challenges of blockchain. The proposed design took advantage of blockchain capabilities to prevent fraud in an information system set up through continuous monitoring and permission management.

Davidson et al. argued that blockchain platforms can be an alternative to common enterprises. Such that Bitcoin could act as a substitution to the traditional centralized bank system and Steemit may be used instead of Facebook in the guise of a content generation platform (Davidson et al., 2018 as cited in Pereira et al., 2019).

There are divergent blockchain platforms that vary in terms of their application domain. Although some can be applied to different use cases while the others can be used in specific industries, are generally categorized into four main types:1) Permissionless transactions only (Bitcoin) 2) Permissionless with smart contracts (Ethereum) 3) Permissioned transactions only (Chain Core) 4) permissioned with smart contracts (Hyperledger Fabric) (Ellervee et al., 2017, as cited in Belotti et al., 2019). In research conducted by Belotti et al. (2019) open-source key blockchain frameworks are listed as; Bitcoin, Ethereum, Hyperledger, Corda, Tendermint, Chain Core, Quorum.

In addition to mentioned blockchain applications and platforms available to get the most out of the continuously growing technology, SETI@home and Folding@home are other widely used cases where computational resources are used to reward participants. (Swan, 2015, as cited in Casino et al., 2019). Moreover, in Primecoin, the need to find computing hashes are substituted by long chains of prime numbers (King, 2013, as cited in Casino et al., 2019). Furthermore, Gogerty and Zitoli proposed a blockchain architecture named Solarcoin in an attempt to inspire renewable energy consumption (Gogerty & Zitoli, 2011, as cited in Casino et al., 2019).

2.4 Adoption of Blockchain in a software system

Although the quality attributes such as security, privacy, throughput, size and bandwidth, performance, usability, data integrity and scalability are required to have a qualified blockchain implementation, the blockchain adoption process involves undertaking some technical limitations and challenges (Koteska et al., 2017).

Before blockchain adoption, the suitability of the underlying technology must be evaluated to make sure it meets the requirements of the applicable area. For this, researchers and experts have suggested numerated frames that can be used to measure the compatibility of blockchain-based applications. For instance, to assess the fitness of blockchain models in the supply chain, EHRs, identity management, and the stock market, Lo et al. designed a framework (Lo et al., 2017, as cited in Casino et al., 2019). Similar work was done by Wüst and Gervais developing a framework to identify blockchain-based development adaptability in specified areas (Wüst & Gervais, 2017, as cited in Casino et al., 2019).

Blockchain technology is suited where the need for a centralized source of trust is completely removed or transferred to any external third party, therefore the process of blockchain adoption begins with trust decentralization. As blockchain has moderate computational power and data storage capability, it is important to decide which data and computation need to be kept on-chain and what type of data must be stored off-chain. Subsequently design decisions regarding blockchain scope, protocol and configuration should be taken along with other scalability and security-related decisions. It is obvious that the inherent properties of blockchain are traded off in the process. However, the type of cryptography used frequently determines the quality of data integrity. Eventually, deployment is another significant step that affects the blockchain-based system's quality attributes (Xu et al., 2017).

Multichain is an open-source blockchain platform that provides users with core code toward developing blockchain-based applications at rapid speed. In addition, it includes permissions management, asset issuance and data sharing functions (Wang & Kogan, 2018). Wang and Kogan (2018) developed a Blockchain-based Transaction Processing System (Bb-TPS) based on the Multichain platform and four Windows servers at Rutgers CAR-Lab. They also explained, initially, a new blockchain model was built on Server 92 which was named "Achain". Next, they connected three other servers to the existing chain. To complete the connection, the three added servers send connection permission requests to Server 92. After the requests are granted, Server 109, Server 116 and Server 117 connect to "Achain" using their public and private keys. In the end, Bb-TPS infrastructure is created in the form of a four-node private blockchain network.

As part of the implementation process, testing happens to ensure the trustiness and reliability of a Blockchain system. In this regard, various criteria must be taken into consideration. According to Koteska et al., the type of blockchain platform (i.e., public, or private) determines the validation level. Such that testing private architectures is more difficult than the public ones. Furthermore, plenty of time must be spent for environment setup if an exact copy of the Blockchain model implementation is not available. There will be a need to perform integration testing to check the consistency of the implementation with other applications. Essentially, the performance of the model must be tested by applying a large number of transactions (Koteska et al.,2017).

2.5 Multi-criteria Decision-making (MCDM) analysis and comparison

2.5.1. Multi-Criteria Decision Making (MCDM)

Some decisions are not easy to make and require plenty of strength and energy. Also, decision-makers will be able to make a better decision only if they have the required amount of information which varies from one decision to the other (Abdulateef et al., 2019).

The decision-making process can be subjective or fundamental as well as structured. A structured decision analysis creates techniques to assist decision-makers in the process of choosing an appropriate action for a specific decision problem. Decision-makers utilize a large number of tools and a basic methodology to turn down the problem into pieces that are easy to manage (Abdulateef et al., 2019).

Therefore, MCDM as a subdivision of operations research considers and compares numerous alternatives and criteria. MCDM is a suitable technique to facilitate the decision-making process with the help of a mathematical model where the decision-makers need to handle the multi-standard problem (Abdulateef et al., 2019).

MCDM methods are recommended solutions aiming to provide support to decision-makers in organizing the problem, comparing, and ranking a set of pre-determined alternatives in terms of their performance and choosing the best alternative using a decision matrix (DM). Recently, a lot of disciplines put in an application of various decision-making theories with a positive result. Decision-makers have been benefited from the multipurpose and heterogeneous nature of MCDM algorithms. Table 2.1 presents the list of MCDM techniques identified in the paper with a brief description of them.

Table 2.1 Description of MCDM methods

MCDM Method	Description	Reference Citations
Analytic Hierarchy Process (AHP)	AHP is "a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales"	Zaidan et al. (2015); Sharma et al. (2020); Kabassi et al. (2020); Kannan et al. (2019); Uzoka & Akinnuwesi (2019); Serhani et al. (2018); Guimarães et al. (2018); Secundo et al. (2017); Bakhouyi et al. (2016); Sun et al. (2016); Minetola et al. (2015); Sun et al. (2014); Sun et al. (2006)
Fuzzy Set Theory	Fuzzy set theory is an extension of classical set theory that "allows solving a lot of problems related to dealing the imprecise and uncertain data"	Sharma et al. (2020); Minetola et al. (2015); Sun et al. (2016); Secundo et al. (2017); Kabassi et al. (2020); Sun et al. (2014); Tavana et al. (2013), Sun et al. (2006)
Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS)	TOPSIS allocates scores to each alternative based on their geometric distance from the positive and the negative ideal solutions.	Zaidan et al. (2015); Kabassi et al. (2020); Kannan et al. (2019); Gupta et al. (2019); Araujo et al. (2018); Sun et al.

MCDM Method	Description	Reference Citations
		(2016); Sun et al. (2014); Sun et al. (2006)
The analytic network process (ANP)	It is a more general form of the analytic hierarchy process (AHP) used in multi-criteria decision analysis. The ANP method focuses mainly on analyzing evaluation criteria and alternative options to make a final decision.	Ariya & Puritat (2020); Lin et al. (2016); Tavana et al. (2013)
Weighted sum model (WSM)	This technique 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.	Zaidan et al. (2015)
Simple Additive Weighting (SAW)	The basic logic of SAW is to obtain the weighted sum of the performance ratings of each alternative overall attribute	Zaidan et al. (2015); Kabassi et al. (2020)
Multiplicative exponential weighting (MEW) or weighted product method (WPM)	It is almost similar to WSM; the only difference between both methods is that addition is the main mathematical operation in WSM, whereas multiplication is the main mathematical operation in WPM.	Zaidan et al. (2015); Kabassi et al. (2020)
Hierarchical adaptive weighting (HAW)	In SAW, each criterion value is divided by the largest criterion value among all alternatives.	Zaidan et al. (2015)
COPRAS (Complex Proportional Assessment) method	It assumes direct and proportional dependence of significance and priority of investigated alternatives on a system of criteria	Bakhouyi et al. (2016); Tavana et al. (2013)
Decision making Trial and Evaluation Laboratory (DEMATEL)	It is a methodology that can be used for researching and solving complicated and intertwined problem groups	Lin et al. (2016)
PrincipalComponent Analysis (PCA)	It can be used to simplify a large number of criteria and can satisfy the hypothesis of AHP/ANP on the independence/dependence of criteria included in the system aspect.	Lin et al. (2016)

Table 2.1, continued

MCDM Method	Description	Reference Citations
VlseKriterijumska Optimizacija IKompromisno Resenje (VIKOR)	The concept of VIKOR is to identify both positive-ideal (the aspired/desired level) and negative-ideal (the worst level) solutions.	Lin et al. (2016)

2.5.2. Analysis of MCDM methods applied in existing studies of all application domains

Table 2.2 provides a comparison of various MCDM methods applied in different papers associated with decision-making and selection. Existing studies were compared based on four perspectives: number of criteria, type of applied MCDM method, practical application, and system/tool. The following questions are defined to analyze the existing studies:

- **Criteria:** Does the study describe the criteria used to compare and assess the alternatives? If Yes: What are the criteria? Any criteria group? How many criteria and sub-criteria?
- **MCDM method:** Does the study include the MCDM method to compare and evaluate the alternatives? If Yes: What is the MCDM method(s)?
- **Practical Application:** Does the study indicate whether the proposed selection methodology, evaluation technique, selection criteria have been applied practically.
- **System/tool:** Does the study specify any systems/tools to support the selection?

All the studies were applied to a particular type of application areas such as cloud service selection, product design selection, evaluation of cultural websites, maintenance strategy selection, software packages selection, LMS (Learning Management Systems), or social media platform selection. Most papers have defined the main criteria groups and then further introduced sub-criteria under each group for evaluation. However, Kannan et al. (2019), Gupta et al. (2019), Araujo et al. (2018), Bakhouyi et al. (2016), Sun et al. (2016) and Sun et al. (2014) only propose evaluation criteria without categorizing them. Serhani et al. (2018) suggested using the QoS attributes provided by the Big Data Task Profile (BDTP) for their selection strategy of cloud services.

The authors have used different MCDM methods for comparison and selection for different application domains. As illustrated in Table 2.2, they usually used a combination of MCDM techniques to compromise the weakness of one with the strengths of another. In some papers, the results derived from different MCDM techniques have been compared. AHP, TOPSIS and Fuzzy set theory are quite popular among the MCDM methods applied in the selected studies.

Except for one study (Sharma et al., 2020), all studies have applied their proposed selection model to real-world case studies and have evaluated the practicability and usefulness of the proposed approach. Serhani et al. (2018) have developed three successive algorithms to support their suggested three phases selection namely: The BDTP-CSPC algorithm, The S_PCSS algorithm, The M_PCSS algorithm. Araujo et al. (2018) developed a tool called MiPACE to support the planning of cloud infrastructures that consider customer service constraints and assist in the decision-making process.

Sun et al. (2016) proposed a Fuzzy User-oriented Cloud Service Selection System (Cloud-FuSeR) that is capable of dealing with fuzzy information and rating Cloud services. Jadhav & Sonar (2011) proposed the HKBS approach for the evaluation and selection of software packages. Decision-makers can make use of this tool for different evaluation activities such as selecting criteria, software user requirements' identification and change, defining the appropriateness of the software package based on user requirements and reutilizing the knowledge or experience.

Table 2.2 Comparison of existing studies that have applied MCDM methods

No	Source	Application area	Criteria No.	MCDM method	Practical application	System/ Tool
1	Ariya & Puritat (2020)	ERP focus on SMEs	3 criteria & 14 sub- criteria	ANP method	Yes	No
2	Sharma et al. (2020)	Cloud Computing adoption in the Indian context	4 criteria & 18 sub-criteria	AHP and FAHP	No	No
3	Kabassi et al. (2020)	Evaluation of cultural websites	3 criteria & 14 sub-criteria	AHP and Fuzzy TOPSIS	Yes	No
4	Kabassi et al. (2020)	Evaluation of cultural websites	3 criteria, 14 sub-criteria	AHP, Fuzzy SAW, and Fuzzy WPM	Yes	No
5	Kannan et al. (2019)	Open-Source Software (OSS) Package Selection	5 criteria	AHP, Teaching–Learning Based Optimization	Yes	No

No	Source	Application area	Criteria No.	MCDM method	Practical application	System/ Tool
				(TLBO), TOPSIS		
6	Gupta et al. (2019)	Software components (COTS, in-house)	16 Attributes	TOPSIS	Yes	No
7	Uzoka & Akinnuwesi (2019)	Software project evaluation and selection	6 major criteria & 14 sub-criteria	AHP methodology	Yes	No
8	Serhani et al. (2018)	Cloud Service Selection	QoS attributes provided by the Big Data Task Profile (BDTP)	AHP and MADM	Yes	1. BDTP-CSPC algorithm 2. S_PCSS algorithm 3. M_PCSS algorithm
9	Guimarães et al. (2018)	Discrete-event simulation software (DESS) selection	7 groups to give a total of 56 items	AHP	Yes	No
10	Araujo et al. (2018)	Cloud computing infrastructures	4	TOPSIS method	Yes	MiPACE
11	Secundo et al. (2017)	Service supplier selection	6 criteria & 24 sub-criteria	fuzzy extended AHP	Yes	No
12	Bakhouyi et al. (2016)	LMS (Learning Management Systems) interoperability	8	AHP, COPRAS	Yes	No
13	Sun et al. (2016)	Cloud service selection	9	fuzzy TOPSIS (ALPHA), fuzzy AHP	Yes	Cloud-FuSeR
14	Lin et al. (2016)	Digital music service platform	5 criteria & 21 sub-criteria	DEMATEL, PCA, ANP, and VIKOR	Yes	No
15	Zaidan et al. (2015)	OS-EMR	7 Reference measures & 29 elements	AHP integrated with WPM, WSM, SAW, HAW, and TOPSIS	Yes	No
16	Zaidan et al. (2015)	OS-EMR	8 criteria & 30 sub-criteria	Integrated AHP and TOPSIS	Yes	No
17	Minetola et al. (2015)	Reverse engineering	3 categories & 10 criteria	fuzzy AHP	Yes	No
18	Sun et al. (2014)	Cloud Service Selection	9	Fuzzy AHP, fuzzy TOPSIS (ALPHA)	No	No
19	Tavana et al. (2013)	social media platform selection	5 criteria & 4 sub-criteria	ANP with fuzzy set theory and COPRAS-G	Yes	No

Table 2.2, continued

No	Source	Application area	Criteria No.	MCDM method	Practical application	System/ Tool
20	Jadhav & Sonar (2011)	Software evaluation and selection	7 groups & 33 sub-criteria	HKBS approach	Yes	HKBS
21	Sun et al. (2006)	product design selection	3 criteria & 7 sub-criteria	Fuzzy set theory, AHP, TOPSIS	Yes	No

2.6 Related studies of blockchain platform selection

Table 2.3 presents the studies that performed research related to the blockchain platform selection. This review only includes the studies that have clearly explained evaluation criteria and how to compare the blockchain platform alternatives using the criteria. The 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 (i.e., Benchmarking, Boolean Decision Tree (BDT) and MCDM methods). MCDM indicates whether the applied technique is a multicriteria decision-making method. Quality attributes denote whether quality attributes are considered for selection and the type of quality attributes are domain-specific (i.e., blockchain platform) or refer to ISO standard. Criteria and alternatives stand for the number of evaluation criteria selected for comparison and the number of platforms alternatives included for comparison and selection. Further analysis of evaluation criteria and alternatives to blockchain platforms are analyzed and discussed in Section 2.6.1 and Section 2.6.2.

Table 2.3 Studies that carried out research related to the blockchain platform selection

ID	Studies	Proposed solution	Decision-making technique	MCDM	Quality Attributes	Criteria	Alternatives
P1	Anh Dinh et al. (2017)	Framework	Benchmarking	No	Domain specific	7	3
P2	Maple & Jackson (2018)	Anatomy	Benchmarking	No	Not defined	3	6

ID	Studies	Proposed solution	Decision-making technique	MCDM	Quality Attributes	Criteria	Alternatives
P3	Kuo, Zavaleta Rojas, Ohno-Machado (2019)	Reference for selection based on PRISMA	Benchmarking	No	Not defined	21	10
P4	Yabo (2016)	Matrix	Benchmarking	No	Not defined	28	25
P5	Macdonald, Liu-Thorrold & Julien (2017)	Comparative analysis using a set of criteria	Benchmarking	No	Domain specific	8	5
P6	Natoli, Yu, Gramoli & Esteves-Verissimo (2019)	Evaluation Framework	Benchmarking	No	Not defined	4	16
P7	Chowdhury et al. (2019)	Taxonomy, Comparative analysis	Benchmarking	No	Domain specific	13	10
P8	Frauenthaler, Borkowski & Schulte (2019)	Framework	WSM	Yes	Domain specific	8	4
P9	Maček & Alagić (2017)	Hybrid evaluation model	AHP	Yes	Domain specific	6	4
P10	Tang, Shi & Dong (2019)	Evaluation model	TOPSIS	Yes	Domain specific	14	30
P11	Staderini Schiavone & Bondavalli (2018)	Requirements-driven methodology with flow diagrams	BDT	Yes	Domain specific	8	4
P12	Pahl, El Ioini, & Helmer (2018)	Framework with decision flow	BDT	Yes	Domain specific	6	6
P13	Wüst & Gervais (2018).	Structured methodology with flow chart	BDT	Yes	Domain specific	6	4
P14	Belotti, Božić, Pujolle & Secci (2019)	Vademecum with decision tree	BDT	Yes	Domain specific	17	7

Table 2.3, continued

ID	Studies	Proposed solution	Decision-making technique	MCDM	Quality Attributes	Criteria	Alternatives
P15	Koens & Poll (2018)	Decision scheme model	BDT	Yes	Domain specific	9	8
P16	Farshidi, Jansen, España & Verkleij (2020)	Decision model	DSS and WSM	Yes	ISO/IEC 25010	121	28

In P1, Anh Dinh et al. (2017) conducted an in-depth evaluation of three significant private blockchains: Ethereum, Parity and Hyperledger Fabric using both two macro benchmarks and four micro benchmarks. The authors' proposed benchmarking evaluation framework, namely Blockbench was the first of its kind and consists of two workloads; a macro benchmark to evaluate application-layer performance, and a micro benchmark to test the lower layers. the framework can be employed to compare different platforms and provide a further understanding of various system design choices. The reasons for choosing Ethereum, Parity and Hyperledger blockchain for the analysis, were their different designs and codebase maturity. Evaluation results concluded that the selected blockchains have limitations in data processing workloads. Furthermore, some obstacles and design trade-offs of the three systems are discussed which can be used in developing better blockchain technologies.

In P2, the anatomy of Blockchain models is discussed by Maple & Jackson (2018). Firstly, they analyzed the existing related papers, followed by generalized anatomy of blockchain solutions which contained essential technological features namely Blocks, Smart Contracts, Transaction Signing, Permissions and Consensus. However, the considered subset of features for the creation of the anatomy does not completely include all blockchain topology models, it can be used as a reference for blockchain platforms evaluation. In the end, the authors discussed some of the key platforms. Since the paper only compared existing technologies and protocols, which architects can only use as a guideline for building blockchain solutions, it does not include any evaluation of the proposed anatomy.

In P3, Kuo et al. (2019) systematically reviewed and investigated the potential uses of blockchain in healthcare or biomedical to highlight the benefits and key features of underlying blockchain platforms in healthcare applications. A method for the systematic review of technology is developed based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement. Search for general-purpose blockchain platforms was mainly conducted on google.com in July 2017. The top 30 retrieved web pages are reviewed and a collection of the blockchain platforms names is extracted from the selected web pages. The candidate names were entered into two online dictionary websites: Dictionary.com and Oxforddictionary.com to check if they are dictionary words or not. For non-dictionary platform names, the Google Count of the name determined the popularity score of the platform. Using the "popularity scores", Top 10 ranked well-known platforms were selected manually for the study. Three authors analyzed the online resources to extract technical features or data items for the selected 10 blockchain platforms and did the pilot test on the two most popular blockchain platforms namely Bitcoin and Ethereum. Their review covered only the crucial features in the healthcare-related blockchain platforms selection, and it needed to include a few other features. Additionally, the proposed selection process which was based on "popularity scores" and a manual screening process might cause a bias against other well-known blockchain platforms. The authors did not present any evaluation for the proposed method, although critical blockchain implementation features are discussed, and the healthcare-related technical features of the introduced platforms are compared.

In P4, Yabo (2016) presented a benchmarking spreadsheet by describing the different types of blockchain players namely Cryptocurrencies, Blockchain platforms, Sidechains, and Distributed ledgers/private blockchains and compared their features against each other. The spreadsheet was built for their blockchain development company customers and was a work in progress. The limitation of papers based on documentation and reports is that they need to be continuously updated because blockchain is a relatively new and fast-evolving technology. The paper does not include any evaluation since it did not propose any method.

In P5, Macdonald et al. (2017) provided a technical overview of how blockchain is applied in Bitcoin cryptocurrency and a comparative analysis of five open-source blockchain platforms using a set of criteria related to usability, flexibility, performance, and potential is made. Moreover, the authors conducted some case studies of blockchain applications to display the blockchain technology's potential rather than Bitcoin. The case studies consider a reputation system, a smart contract system and a digital content distribution.

In P6, the evaluation framework proposed by Natoli et al. (2019) discusses system models, applicable properties and criteria using three complete and essential components which are generic to all systems: membership selection, consensus mechanism and structure. Decomposition and categorization of the blockchain complex helped to explain the blockchain complex in a simpler way. The framework provides clear and knowledgeable benchmarking overviews of the design principles and properties behind the analyzed systems and draws a picture of the present blockchain proposals' outlook. The paper does not include any evaluation since it did not propose any method.

In P7, Chowdhury et al. (2019) presented a comprehensive comparative analysis of selected major DLT platforms by paying special attention to some of their main quantitative and qualitative criteria. The benchmarking evaluation aims to consider useful when choosing the best-fitting blockchain platform in a specific application domain. The paper does not include any evaluation since it did not propose any method.

In P8, the framework introduced by Frauenthaler et al. (2019) monitors multiple blockchains and points out the suitable blockchain based on user-defined functional and non-functional requirements, providing alteration during runtime. To provide the user with the ability to prioritize the metrics, they demonstrated a weighted ranking system that is used to estimate the amount of blockchain's usefulness derived from user-defined weights and score assignments. To cover the system shortage for not taking into consideration of the blockchain's required specification (e.g., an interblock time) that needs to be met unconditionally, the Metric Validation Function (MVF) is proposed but the solid implementation of the function needs to be contributed by the user. Nonetheless, the introduced framework is not equipped with the ability to relocate smart contracts from one chain to the other. The authors have presented four evaluation scenarios to investigate the proposed framework benefits regarding cost, performance, and trust. The framework's reaction is analyzed to variations of blockchain metrics in addition to its ability to handle changes in user requirements.

In P9, Maček & Alagić (2017) introduced a hybrid AHP model to compare and evaluate Bitcoin cryptocurrency with existing generic online payment systems such as e-banking, m-banking, and e-commerce based on their security posture. Information security professionals used VECTOR matrix approach to identify and prioritize information security risks and then integrated the VECTOR technique into the Analytic Hierarchy Process (AHP) method to evaluate criteria of alternatives. Although to further validate and prove the likelihood of the discussed model, more use cases need to be conducted based on the proposal. Moreover, the VECTOR method for prioritization of critical IT assets or risks, integrated into the AHP model suggested in the study has applicability limitations in the specific information security areas. The applicability of the proposed AHP model with integrated fixed VECTOR criteria for alternative ranking is evaluated by a comparison of the security characteristics of Bitcoin cryptocurrency with different internet payment systems. For this, a limited number of information security experts who only had experience or are engaging in e-banking, m-banking, and e-commerce systems in the bank, were selected to examine the applicability and functionality of the proposed model.

In P10, Tang et al. (2019) developed a model for public blockchains' evaluation for related researchers and managers' references. To this end, they suggested an entropy method to assign weights for various indicators, a let-the-first-out (LFO) strategy to cut down the criteria of the positive ideal solution and rate thirty public blockchains based on the TOSIS approach. Technology, recognition, and activity are the main indicators of the model, but the two sub-indicators of technology are taken from China Center for Information Industry Development (CCID) which resulted in small weights due to their limited number. However, there is a need to focus on designing more reasonable indicators as it makes the evaluation more comprehensive. The authors selected thirty public blockchains for the evaluation of the proposed model. CCID global public blockchain technology assessment index (CCID, 2018c), TokenInsight (TokenInsight, 2018), CoinMarketCap (CoinMarketCap, 2018), Google Trends (Google Trends, 2018), GitHub (GitHub, 2018), and Twitter (Twitter, 2018) from January 2015 to August 2018 are where data were collected from. The evaluation model is used to rank the selected public platforms in terms of technology, recognition, and activity. Eleven second-level indicators formed these three first-level indicators. The entropy method is used to determine the weights of different indicators and the TOPSIS method is used to evaluate the platforms.

In P11, Staderini et al. (2018) supported the system designer to decide whether blockchain technology can be applied to the specific problem based on system requirements analysis. The proposed approach is illustrated in the form of a flowchart of processes. The first step is to analyze the requirements and determine whether blockchain could be recommended or not recommended for the specific problem. Immutability, integrity, and non-repudiation criteria can also be added. If blockchain adoption is recommended, reading and writing operations are considered as the main criteria in the blackchin choice step. Quality attributes such as scalability, interoperability and flexibility, performance, decentralization, availability, anonymity, privacy, confidentiality, transparency, and trustless can be taken into consideration as a sub-process of this phase. Eventually, the designer must decide on an appropriate configuration for the choice output. This last phase can be done in five stages which are: i) Consensus Algorithm, ii) Smart Contracts, iii) Security Measures, iv) Privacy and Anonymity, and v) Data Computation and Storage. The automatization of the proposed methodology is necessary to form a valid and useful appliance for the blockchain platform selection problem. The proposed methodology is not evaluated.

In P12, Pahl et al. (2018) have developed a BDT-based decision framework that can be used to aid practitioners in the decision-making process of the suitability of blockchain technology for their application and choosing the specific category of platforms (public permissionless, public permissioned, and private permissioned). Moreover, the study systemically identifies blockchain advantages for IoT and challenges that could be solved by applying blockchain technology. They compared existing systems based on some important properties and their relative impact on quality in an IoT context. The evaluation of three different IoT companies and their operational environment further validates the usefulness of the proposed framework. The framework is used to check different aspects of each context and disclose if the company leverages blockchain technology or not.

In P13, Wüst and Gervais (2018) suggested a structured methodology with a flow chart to determine the most fitting technical solution in a specified context. The authors differentiate between permissionless (e.g., Bitcoin/Ethereum) and permissioned (e.g., Hyperledger/Corda) blockchains and a centrally managed database by comparing some of their criteria. Furthermore, three use cases - Supply Chain Management, Interbank and International Payments, and Decentralized Autonomous Organizations were analyzed by considering the recommended methodology. They have applied the proposed methodology to these three well-known application scenarios and evaluated how a blockchain solution seems sensible in terms of technical, security and privacy implications.

In P14, Blotti et al. (2019) introduced a general blockchain vademecum and provided comprehensive literature of recent blockchain implementations beyond Bitcoin. The vademecum equips the reader with sufficient information about when to use blockchain, which solution to use, and how to use it, based on use-case requirements. Additionally, the authors explained how to use major existing and open source blockchain networks such as Bitcoin, Ethereum, Hyperledger, Corda, Tendermint, Chain Core, Quorum for the proposed vademecum logic. Moreover, the authors applied the introduced When-Which vademecum logic to three use case applications in networking, supply-chain and, communications and described how it resulted in successively selecting permissionless, open-permissioned and, fully permissioned blockchain implementations.

In paper 15, Koens and Poll (2018) analyzed 30 existing schemes and highlighted that most of them did not consider the alternatives to blockchain-based solutions. Their suggested BDT-based decision scheme model helps to decide the type of database namely public permissionless blockchain, distributed database, and central database. The proposed improved scheme is aimed to provide an answer for the following three questions: Should you use a blockchain? If so, which type of blockchain is best? If not, which alternative database technology is best? Although the authors have presented an evaluation of 30 blockchain decision schemes and classified them by the type of answers they provided to the questions, and listed down the contradictions between some of them, they did not evaluate their proposed new scheme.

In P16, Farshidi et al. (2020) presented a decision model for the blockchain platform selection problem and evaluated it using three real case studies at three software organizations based on their requirements and priorities. Decision-makers can employ the proposed framework to build decision models for MCDM problems and it consists of six main steps:

1. Identification of the objective.
2. Features' selection.
3. Alternatives' selection.
4. Weighing method selection.
5. Aggregation method application.
6. Decision-making based on the aggregation results.

The DSS and the decision model for the blockchain platform selection problem were evaluated by thirteen experts which were selected and interviewed based on their experience. The experts included three DSS experts, four blockchain researchers from Dutch research institutes, two blockchain developers, and four blockchain consultants or public speakers. Therefore, the decision model is built and validated primarily based on the knowledge acquired from the blockchain experts during the interview. The effectiveness and usefulness of the decision model are evaluated by conducting three real industry case studies at three blockchain-based software development companies. The case study participants are asked to identify some possible blockchain platforms for their software companies by investigating into platforms during several internal expert meetings before the employment of DSS. The results of the DSS are compared with the ranked shortlist by case-study participants. The proposed model provides more apprehension into the blockchain platform selection process and reduces the time and cost of the decision-making process. Although, performance testing needs to be performed by software-producing organizations to find the best-suited blockchain platform for their software products.

2.6.1 Comparison of related studies based on evaluation criteria

In this section, selected literature is compared with features and quality attributes selected as criteria for evaluation and comparison of the different blockchain platforms.

2.6.1.1 Features

There are many features supported by different blockchain platforms. In this research, a list of features was identified from existing studies Table 2.4 analyses the features that were used as evaluation criteria in existing studies. To summarize the analysis, Table 2.4 only includes categories of blockchain features to analyze the features that are selected to be compared in the existing studies. Features are categorized as follows:

- Blockchain Network Types:
    - Features: public blockchain, private blockchain, permissioned, permissionless, federated, consortium blockchains and hybrid blockchains
- Consensus Mechanisms: Consensus forms the core property of the blockchain where the valid blocks are agreed upon to be appended to the chain. The finding of a

consensus has been identified as a central element of the transaction process in a Blockchain.

  - Features: 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), Directed acyclic graph (DAG), Kafka, Mining Diversity

- Blockchain Tokens: Cryptocurrency tokens on the blockchain.
  - Features: Cryptographic tokens, Naïve tokens, Non-native protocol tokens, dApp tokens, Cryptocurrency tokens, Network tokens, Investment tokens, Asset-based tokens, Network value tokens, Share-like tokens, Usage tokens, Work tokens, Utility tokens, Hybrid tokens, Security tokens
- Blockchain Layers: A high-level representation of the blockchain framework, subdivided into the network layer, data layer, and application layer to assess blockchain and consider the detailed techniques of the data and network layers of the framework as well as application areas.
  - Features: Protocol layer, Network layer, Application layer
- Cryptocontract: One of the potentials of blockchain technology is seen in the automation of digital processes using a computer program with a set of agreements on blockchain networks based on the concept of cryptography. This automation is reached by so-called Cryptocontract or Smart Contracts. However, the term is usually used to describe a process that carries out certain activities when special states occur. Wieninger et al. (2019) used the word "Turing complete" to present a smart contract.
  - Features: Smart-contract, Virtual machine, Turing completeness
- Programming language: Supported blockchain programming or scripting language to develop applications, tokens, or smart contracts.
  - Features: Solidity, Python, Golang, Java, JavaScript, .Net, C++
- Privacy/Anonymity feature in the blockchain:
  - Features: Zero-knowledge proof/protocol, zk-SNARK, Ring signatures
- Interoperability in Blockchain:

    - Features: Atomic swap, Cross-chain technology, Enterprise system integration
- Resilience feature in Blockchain:
    - Features: Hard fork resistant, Spam attack resistant, Sybil attack resistant, Quantum attack resistant, Instant transaction finality
- Scalability feature in Blockchain:
    - Features: On-chain transactions, Off-chain transactions, Off-chain state channels, Sidechains, Sharding, Plasma-chain, Data Computation and Storage
- Structure: The structure defines the way transactions and events are recorded in blockchain systems.
    - Features: block types (Bitcoin-NG, ComChain), parallel block processing, or new communication patterns
- Data model
    - Features: UTXO, Account, UTXO$^+$, Key-value

Table 2.4 Comparison of related studies based on the main category of blockchain features as evaluation criteria

ID	Blockchain Network Types	Consensus Mechanisms	Blockchain Tokens	Blockchain Layers	Cryptocontract	Programming language	Privacy feature	Interoperability feature	Resilience feature	Scalability feature	Structure	Data Model
P1	X	√	X	√	√	√	X	X	X	X	X	√
P2	√	√	X	X	√	X	X	X	X	√	√	X
P3	√	√	√	X	√	√	√	X	X	X	X	X
P4	√	√	√	X	√	√	√	X	√	X	X	X
P5	X	√	√	X	X	X	X	X	X	X	X	X
P6	√	√	√	X	√	X	√	X	X	√	√	X
P7	√	√	X	X	X	X	√	X	√	X	X	X
P8	X	X	X	X	X	X	X	X	X	X	X	X
P9	X	X	X	X	X	X	X	X	√	X	X	X
P10	X	X	X	X	X	X	X	X	X	X	X	X
P11	√	√	X	X	√	X	√	√	X	√	X	X
P12	√	√	X	X	√	X	√	X	X	√	X	X
P13	√	√	√	X	√	X	X	X	X	X	X	X
P14	√	√	√	X	√	√	X	X	X	√	X	√
P15	√	X	X	X	X	X	X	X	X	√	X	X
P16	√	√	√	√	√	√	√	√	√	√	X	X
Total	11	12	7	2	10	5	7	2	4	7	2	2

A concise summary of the comparison of related studies based on the main category of blockchain features as evaluation criteria is shown in Table 2.4. It was noted that the features, Consensus Mechanisms, Blockchain Network types, and Cryptocontract are the top three discussed categories of blockchain features in the analyzed literature.

P9 and P10 did not include features in their comparison, blockchain platforms are evaluated and compared using quality attributes as evaluation criteria. In P9, the proposed AHP model with fixed VECTOR open source and a simple method for qualitative risk assessment is used for the evaluation of critical online transaction systems. The evaluation model in P10 is used to rate public blockchains for technology, recognition, and activity scope.

Studies that have applied the BDT approach normally will first have the decision flows to determine the network types. 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 only one solution at the end of each evaluation. Furthermore, decision-makers cannot prioritize decision criteria based on their preferences.

2.6.1.2 Quality attributes

Existing studies take some quality attribute measures into account to assess and select suitable blockchain platforms for their projects, applications and use cases. In this section, the quality attributes from System and Software Quality Models defined in ISO/IEC25010 are used to identify what are the main quality attributes that have been considered as evaluation criteria in the existing studies. ISO/IEC 25010 consists of the Quality in use model (ISO, 2011) and Product quality model (ISO, 2011). These two models provide a set of quality attributes relevant to a wide range of stakeholders. The quality in use model (ISO, 2011) characterizes the impact that the product has on stakeholders and the impact is determined by the quality of the software, hardware, and operating environment. On the other hand, the product quality model characterizes static properties of the software product and dynamic properties of computer systems including software. Quality attributes of the product quality model (ISO, 2011) influence the ones in the quality in use model (ISO, 2011).

Product Quality Model (ISO, 2011) consists of eight main quality attributes. Some domain-specific quality attributes are mapped into the main quality attributes to ease the comparison of the quality attributes selected by the existing studies.

- **Functional suitability**: "Degree to which a product or system provides functions that meet stated and implied needs when used under specified conditions"
  - Sub-characteristics: Functional completeness, Functional Correctness, Functional appropriateness
- **Performance efficiency**: "Performance relative to the amount of resources used under stated conditions"
  - Sub-characteristics: Time-behavior (response and processing times, throughput rates, latency, transaction speed), Resource utilization, capacity, cost-efficiency
  - Domain-specific sub-characteristics: Transaction speed, Cost-efficiency
- **Compatibility**: "Degree to which a product, system or component can exchange information with other products, system or components, and/or perform its required functions while sharing the same hardware or software environment"
  - Sub-characteristics: Co-existence, Interoperability
- **Usability**: Users to achieve specified goals with effectiveness, efficiency, and satisfaction
  - Sub-characteristics: Appropriateness recognizability, Learnability, Operability, User error protection, User interface aesthetics, Accessibility
- **Reliability**: "Degree to which a system, product or component performs specified functions under specified conditions for a specified period of time"
  - Sub-characteristics: Maturity, Availability, Fault tolerance, Recoverability
- **Security**: "Degree to which a product or system protects information and data so that persons or other products or systems have the degree of data access appropriate to their types and levels of authorization)
  - Sub-characteristics: Confidentiality, Integrity, Non-repudiation, Accountability, Authenticity (similar to Identity and Auditability)
  - Domain-specific sub-characteristics: Immutability, Auditability
- **Maintainability**: "Degree of effectiveness and efficiency with which a product or system can be modified by the intended maintainers"
  - Sub-characteristics: Modularity, Reusability, Analyzability, Modifiability, Testability
  - Domain-specific sub-characteristics: upgradability, sustainability
- **Portability**: "Degree of effectiveness and efficiency with which a system, product or component can be transferred from one hardware, software or other operational or usage to another"
  - Sub-characteristics: Adaptability (include the scalability of internal capacity), Installability, Replaceability

Quality in use model (ISO, 2011) comprises five main quality attributes:

- **Effectiveness**: "Accuracy and completeness with which users achieve specified goals"
- **Efficiency**: "Resources expended in relation to the accuracy and completeness with which users achieve goals"

- **Satisfaction**: “Degree to which users’ needs are satisfied when a product or system is used in a specified context of use”
    - Sub-characteristics: Usefulness, Trust, Pleasure, Comfort
- **Freedom from risk**: “Degree to which a product or system mitigates the potential risk to economic status, human life, health, or the environment”
    - Sub-characteristics: Economic risk mitigation, Health and safety risk mitigation, Environmental risk mitigation
- **Context coverage**: “Degree to which a product or system can be used with effectiveness, efficiency, freedom from risk and satisfaction in both specified contexts of use and in contexts beyond those initially explicitly identified”
    - Sub-characteristics: Context completeness, Flexibility

Domain-specific quality attributes or non-functional criteria not covered by ISO/IEC25010:

- **Product**: A product can be defined as anything that we can offer to a market for attention, acquisition, use or consumption that could satisfy a need or want.
    - Guarantees, Parameterialization, Software License, Special Hardware Requirement, Energy Consumption, Technology Maturity, Complexity, Deployment
- **Supplier**: “A party that supplies goods or services. A supplier may be distinguished from a contractor or subcontractor, who commonly adds specialized input to deliverables.”
    - Organizational Structure, Reputation, Positioning and Strength, Support, Services offered, Market Capitalization/Popularity in the market, Governance (development decisions, etc.), Documentation, Development
- **Cost**: It outlines the associated cost incurred, if any, for any transaction to process or store data in the ledger. Cost is often referred to as “transaction fee” in the blockchain domain.
    - Network cost, Licensing cost, Platform cost, Implementation cost, Processing cost, Transaction fees, Storage cost
- **Size**: Block size indicates the maximum allowed size of a block in a DLT system. A higher block size indicates a higher data processing capability for a particular DLT system.
    - Network Size, Block Size
- **Privacy**: Privacy concerns in the blockchain.
    - Anonymity, Transparency, Openness

Table 2.5 include main quality attributes extracted from ISO/IEC205010, some domain-specific quality attributes and non-functional criteria that were identified in the existing studies for blockchain platforms selection. Sub-characteristics are excluded to simplify the comparison.

Table 2.5 Comparison of related studies based on quality attributes as evaluation criteria

ID	Functional Suitability	Performance efficiency	Compatibility	Usability	Reliability	Security	Maintainability	Portability	Effectiveness	Satisfaction	Freedom from risk	Context coverage	Product	Supplier	Cost	Size	Privacy
P1	X	√	X	X	√	√	X	X	X	X	X	X	X	X	X	√	X
P2	X	√	X	X	√	√	X	√	X	X	X	X	√	√	X	X	X
P3	X	√	X	X	X	X	X	X	X	X	X	X	√	√	X	X	√
P4	X	√	X	√	X	√	X	X	X	X	X	X	√	√	√	X	√
P5	X	√	X	√	X	√	X	√	X	X	X	√	X	√	X	X	X
P6	X	X	X	X	√	√	X	√	X	√	X	X	√	√	√	X	√
P7	√	X	X	X	X	√	√	X	X	√	X	X	√	√	√	√	√
P8	X	√	X	X	X	√	X	X	X	X	X	X	X	√	√	X	X
P9	X	X	X	X	√	√	X	X	X	X	√	X	X	√	X	X	X
P10	X	√	X	√	X	√	X	X	X	X	X	X	√	√	X	X	X
P11	X	√	√	X	√	√	X	√	X	√	X	√	X	X	√	X	√
P12	X	√	√	X	X	√	X	√	X	X	X	X	X	√	√	√	√
P13	X	√	X	X	√	√	X	X	X	√	X	X	X	X	X	X	√
P14	X	√	X	X	X	√	√	X	X	X	X	√	√	√	X	X	X
P15	X	√	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P16	√	√	√	√	√	√	√	√	X	X	X	X	√	√	√	X	X
Total	2	13	3	4	7	14	3	6	0	4	1	3	8	12	7	3	7

A concise summary of the comparison of related studies based on quality attributes as evaluation criteria is shown in Table 2.5. It was noted that the three quality attributes: Security, Performance efficiency, reliability and domain-specific quality attributes or non-functional criteria such as supplier, product, privacy, and cost are discussed by most of the studies when choosing the platform which best fits the needs of their project at hand.

Although blockchain platforms are evaluated and compared using quality attributes as evaluation criteria in almost all analyzed literature, Effectiveness from the Quality in use model (ISO, 2011) which includes accuracy and completeness is not discussed in any study. Freedom from risk and functional suitability are the quality attributes that are considered by one and two studies, respectively.

2.6.2 Comparison of related studies based on alternatives (blockchain platforms)

Table 4 shows a list of open source blockchain platforms that are available in the market and have been included as alternatives in the existing studies for comparison and selection. It is a list of potential alternatives that can be used in the decision-making process for the selection of blockchain platforms in this research. Based on Table 2.6, it can be concluded that Ethereum, R3 Corda, Hyperledger platforms, MultiChain, Ripple and Bitcoin are popular blockchain platforms that have always been shortlisted as alternatives.

Table 2.6 Open source blockchain platforms (adapted from Farshidi, Jansen, España & Verkleij, 2020)

No.	Blockchain platform	Public	Private	Permissioned	Permissionless	URL	Included as alternatives
1.	Ethereum	√	√	√	√	www.ethereum.org	P1, P2, P3, P4, P5, P6, P7, P8, P10, P12, P13, P14, P15, P16
2.	R3 Corda	X	√	√	X	www.corda.net	P2, P7, P13, P14, P15, P16
3.	JPMorgan Quorum	X	√	√	X	www.jpmorgan.com	P2, P14, P16
4.	Hyperledger platforms	√	√	√	√	www.hyperledger.org	P1, P2, P3, P4, P5, P7, P11, P12, P13, P14, P16
	Hyperledger (Fabric)	X	√	√	X	www.hyperledger.org	P2, P5, P7, P11, P12, P13
	Hyperledger (Sawtooth)	√	√	√	√	www.hyperledger.org	P2, P5, P7
5.	BigChainDB	X	√	√	X	www.bigchaindb.com	P4, P16
6.	MultiChain	X	√	√	X	www.multichain.com	P2, P3, P4, P7, P16
7.	HydraChain	X	√	√	X	www.github.com/HydraChain	P4, P16
8.	Chain	X	√	√	X	www.chain.com	P14, P16
9.	Symbiont	X	√	√	X	www.symbiont.io	P16
10.	Stratis (Azure Baas)	X	√	√	X	www.stratisplatform.com	P10, P16
11.	OpenChain	X	√	√	X	www.openchain.org	P16
12.	NEO	√	X	X	√	www.neo.org	P10, P16
13.	Cardano	√	X	X	√	www.cardano.org	P10, P16

No.	Blockchain platform	Public	Private	Permissioned	Permissionless	URL	Included as alternatives
14.	Stellar	√	X	X	√	www.stellar.org	P4, P10, P16
15.	Ripple	√	X	√	X	www.ripple.com	P3, P4, P10, P12, P15, P16
16.	Bitshares	√	X	X	√	www.bitshares.org	P10, P16
17.	QTUM	√	X	X	√	www.qtum.org	P10, P16
18.	ICON	√	X	√	√	www.icon.foundation	P16
19.	VeChain	√	X	√	X	www.vechain.org	P16
20.	IOTA	√	X	X	√	www.iota.org	P7, P10, P16
21.	Factom	√	X	X	√	www.factom.org	P16
22.	Cosmos Network	√	X	X	√	www.cosmos.network	P16
23.	Lisk	√	X	X	√	www.lisk.io	P4, P10, P16
24.	Waves Platform	√	X	X	√	www.wavesplatform.com	P10, P16
25.	Wanchain	√	X	√	√	www.wanchain.org	P16
26.	Neblio	√	X	√	√	www.nebl.io	P16
27.	Zilliqa	√	X	X	√	www.zilliqa.com	P16
28.	Komodo	√	X	X	√	www.komodoplatform.com	P10, P16
29.	Bitcoin	√	X	X	√	www.bitcoin.org	P3, P4, P6, P7, P8, P9, P10, P12, P13, P14, P15
30.	Parity	√	√	√	√	www.parity.io	P1
31.	Zcash	√	X	X	√	www.z.cash	P3, P4, P10
32.	Litecoin	√	X	X	√	www.litecoin.com	P3, P4, P10
33.	Dash	√	X	X	√	www.dash.org	P3, P10
34.	Peercoin	√	X	X	√	www.peercoin.net	P3, P4, P6
35.	Monero	√	X	X	√	www.getmonero.org	P3, P10
36.	Nxt	√	X	X	√	www.jelurida.com/nxt	P4
37.	Corda	X	√	√	X	www.corda.net	P4
38.	Billon	X	√	√	X	www.billongroup.com	P4
39.	Enigma	X	√	√	X	www.enigma.co	P4
40.	Tendermint	X	√	√	X	www.tendermint.com	P4, P6, P14
41.	BlockStream Elements	√	X	X	√	www.elementsproject.org	P5
42.	Eris	X	√	√	X	www.erisindustries.com	P5, P12
43.	PeerCensus	√	X	√	√	https://www.frontiersin.org/articles/10.3389/fbloc.2020.00011/full	P6
44.	Permacoin	√	X	X	√	https://github.com/input-output-hk/Scorex/wiki/Permacoin-Implementation	P6
45.	BurstCoin	√	√	X	√	www.burst-coin.org	P6

Table 2.6, continued

No.	Blockchain platform	Public	Private	Permissioned	Permissionless	URL	Included as alternatives
46.	SpaceMint	√	X	X	√	https://github.com/kwonalbert/spacemint	P6
47.	ByzCoin	√	X	√	√	https://github.com/dedis/cothority/tree/master/byzcoin	P6
48.	HoneyBadger BFT	X	X	√	X	https://github.com/amiller/HoneyBadgerBFT	P6
49.	Solida	√	X	√	√	https://arxiv.org/abs/1612.02916	P6
50.	Ouroboros	√	X	X	√	https://cardano.org/ouroboros/	P6
51.	RepuCoin	√	√	X	√	https://github.com/lpfloyd/repuify	P6
52.	RedBelly Blockchain	√	X	√	√	www.redbellyblockchain.io	P6
53.	Expanse	√	√	√	√	www. expanse.tech	P8
54.	EOS	√	√	√	√	www.eos.io	P10
55.	Nebulas	√	X	X	√	www.nebulas.io	P10
56.	NEM	√	√	√	√	www.nem.io	P10
57.	Nano	√	√	√	√	www.nano.org	P10
58.	Steem	√	√	√	√	www.steem.com	P10
59.	Verge	√	√	X	√	www.vergecurrency.com	P10
60.	Siacoin	√	√	X	√	www.sia.tech	P10
61.	Bytecoin	√	√	X	√	www.bytecoin.org	P10
62.	Decred	√	X	X	√	www.decred.org	P10
63.	Ark	√	√	√	√	www.ark.io	P10
64.	AlgoRand	√	X	X	√	www.algorand.com	P6

2.7 Research gaps in the related studies of blockchain platform selection

Among the selected literature, some studies suggested a decision-making method or systematic approaches based on BST and MCDM to assist in the decision-making process. Most pointed out that MCDM methods can be applied to evaluate and compare a collection of blockchain platforms against each other. However, their suggested methods are having some limitations which are outlined as follows:

P1 is only limited to private blockchain platforms based on benchmarking experiments. Since performance testing and security testing are time-consuming and difficult for novice decision-makers. P10 only focuses on the public blockchain, and evaluation criteria related to non-functional criteria. P15 mainly focuses on decision schemes to select suitable alternatives based on blockchain network type (public, private, permissioned, permissionless).

P1, P2, P3, P4, P5, P6, P7 are based on benchmarking experiments. As blockchain is a relatively new and fast-evolving technology, so documentation is often out of date or not available; therefore, studies based on documentation and reports are likely to become outdated soon and should be kept up to date continuously.

P11, P12, P13, P14, P15 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 only one solution at the end of each evaluation. Furthermore, decision-makers cannot prioritize decision criteria based on their preferences.

P16, the DSS offers a short-ranked list of feasible blockchain platforms, software-producing organizations should perform further investigations, such as performance testing, to find the best-fitting blockchain platform for their software products. Furthermore, the results of MCDM approaches are valid for a specified period; therefore, the results of such studies, by blockchain technology advances, will be outdated. In the proposed solution, the knowledge base must be kept up to date, which is also quite challenging.

In P9**,** the proposed hybrid AHP model with fixed VECTOR criteria calculates weights and priorities according to only qualitative types of criteria compared based on informed judgements (Maček & Alagić ,2017). Only qualitative types of criteria can be represented by fixed VECTOR criteria. Other common criteria relevant for online transaction systems, such as authentication, authorization, confidentiality, integrity and non-repudiation, and availability need to be used as additional criteria for alternatives' evaluation 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.

The introduced weighted ranking system in P8 helps to calculate blockchain's benefit based on user-defined weights and score assignments. The weighted sum model (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. A major criticism of the WSM is the simplicity of the method which results in a noticeable amount of flexibility compromising the accuracy of the prioritization model. As there is not a standard for measuring previous or future scores., therefore each time criteria change, the scores will also be changed. (What is the Weighted Scoring Model? (2020). Retrieved 11, 6, 2021, from https://productfolio.com/weighted-scoring/)

In P10, the Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS) method is used for alternative ranking. A key problem with TOPSIS is its inability to issue criteria weights and to perform consistency checks on judgements (Zaidan et al., 2015). Hence the entropy method is used for the calculation of the different indicators' weights in the study.

2.7.1 Summary of research gaps

The following points are the summary of the identified research gaps from the literature.

- In BDT-based schemes, which are mostly suggested to determine the type of database, the number of criteria is limited, and it only offers one solution at the end. Moreover, decision-makers cannot prioritize decision criteria based on their preferences.
- Decision-making techniques based on benchmarking experiments seem to be not useful for a long period since blockchain is a fast-evolving technology, and documentation is often outdated soon or even sometimes is not available.
- Related studies often focus on one type of criteria, i.e., Functional (features) or Non-functional (quality attributes).
- Both functional (features) and non-functional criteria (quality attributes) are rarely used in combination when comparing different blockchain platforms.

- Only a few papers used multi-criteria decision making (MCDM) techniques and rigid mathematical foundations like AHP, TOPSIS in their proposed framework for the blockchain platform selection problem.
- None of the studies that carried out research related to the blockchain platform selection, used a combination of MCDM methods, in order to overcome the difficulties of one method with the other.

2.8 Summary

This chapter reviewed and discussed background and studies that are closely related to the design of a systematic selection method for blockchain platforms. It covers an overview of the emerging technology, challenges and benefits, critical evaluation features and quality attributes, existing alternatives (Blockchain platforms), various MCDM techniques that were used in comparison and selection of different Blockchain platforms. Besides the comprehensive background, the recent related studies are analyzed based on applied MCDM methods, evaluation criteria and alternatives at the end of the chapter. The next chapter will discuss the research methodology used to achieve the objectives of this research.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter illustrates the methodology used to conduct this research. The overview consists of a series of research activities as presented in Section 3.2. The overview briefly describes all steps that have been taken to conduct this study. The details of each step are presented from Section 3.3 to Section 3.6. A summary is presented at the end of the chapter.

3.2 Overview

This research aims to deal with the blockchain platform selection problem by proposing a systematic selection method for comparing and choosing the best blockchain platform that meets the specified requirement. The methodology used to achieve the objective of this study is summarized in Figure 3.1. The steps that carried out for conducting this research are as follows:

a) Step 1: Literature review (Section 3.3)

i. Review of the existing blockchain applications and platforms
ii. Identify potential criteria for comparison and selection of blockchain applications and platforms
iii. Investigate decision-making methods such as multicriteria decision-making method, fuzzy-based methods
iv. Review related studies

b) Step 2: Identify the research gap (Section 3.4)

c) Step 3: Propose a selection method for comparing and selecting blockchain platforms. (Section 3.5)

d) Step 4: Evaluate the accuracy and applicability of the proposed selection method. (Section 3.6)

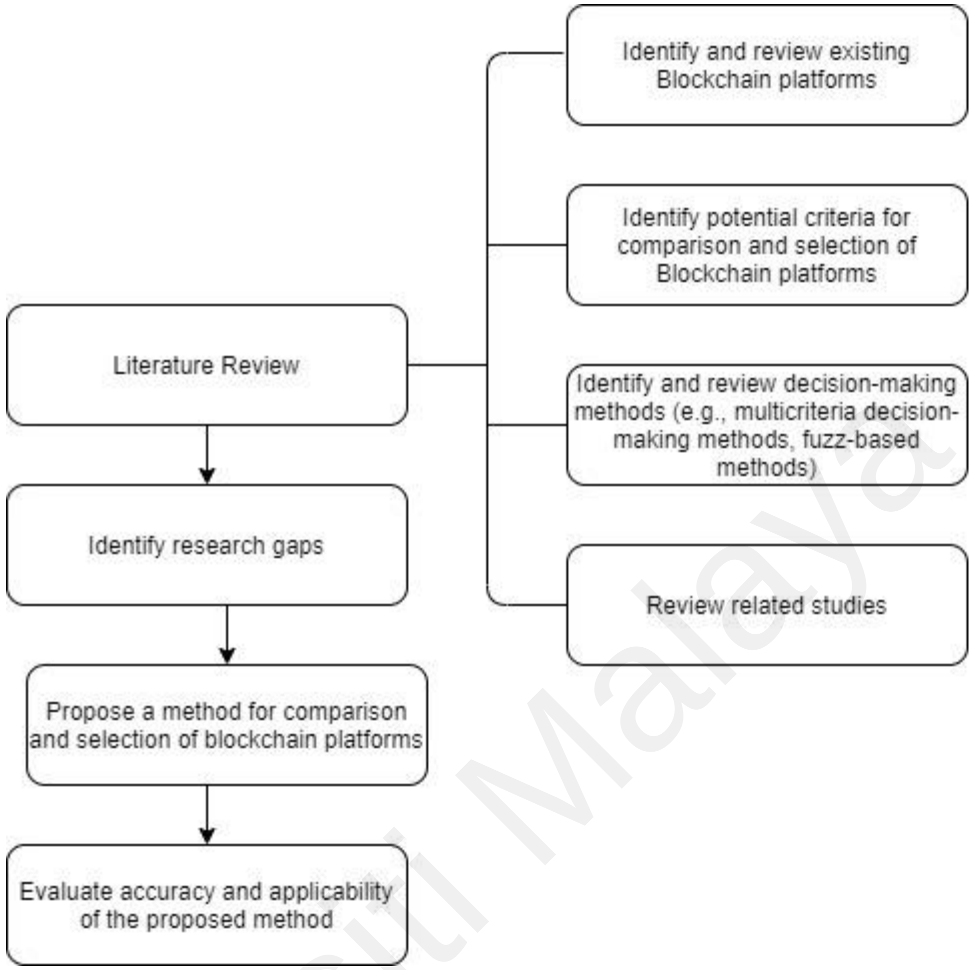

Figure 3.1 Flow Chart of Research Activities

3.3 Literature Review:

A literature review is a process of obtaining information in related areas, which is carried out by previous researchers. Information related to the Distributed Ledger Technologies (DLT) and blockchain definition, advantages, and drawbacks, characteristics of the new technology, platforms and applications and the way they could be adopted, existing blockchain taxonomies were thoroughly reviewed and analyzed to better understand the subject area and to help to conceptualize the research problem more clearly and precisely. The process of reviewing the blockchain applications and platforms is intended to identify desirable features, potential selection criteria and identify candidate blockchain applications and platforms for comparison and selection. Additionally, existing multi-criteria decision-making (MCDM) techniques and fuzzy-based methods were reviewed to support the comparison, evaluation, and selection of blockchain platforms. Also, types of decision-making methods that are commonly used for the selection of applications, technologies, and platforms were analyzed. The existing approaches for MCDMs were then compared and the most appropriate one was adopted for this study. Besides, existing studies that were related to blockchain platform selection were identified, reviewed, and compared. The selection criteria, blockchain platforms and approach proposed in the related studies were analyzed.

The search for papers has been performed in several digital libraries. This study conducted a literature review on journal articles, technical reports, book chapters, and books to understand all areas related to the blockchain comparison and selection and then propose a new selection method for blockchain platform selection. The search was conducted in the following digital libraries:

- IEEE Xplore
- SpringerLink
- Science Direct
- ACM
- Web of Science.
- ISI Web of Knowledge
- Google Scholar.
- Scopus

3.3.1 Search keywords

Different keywords were used to find out about the blockchain technology applications and platforms. The keywords that were used include the blockchain, Distributed Ledger Technologies (DLT), multi-criteria decision-making method, MCDM techniques.

3.3.2 Inclusion criteria

As blockchain is an emerging technology most papers are published recently. The literature was selected based on their relation to comparison, evaluation, and selection of the blockchain applications, technologies, and platforms to develop a blockchain-based system, which includes the blockchain platforms features and quality attributes, different types, and taxonomies of blockchain models, its implementation in different areas of practice, challenges, and limitations of adopting the emerging technology in various high-tech manufacturing companies. The search covered a period from 2016-2020 for blockchain-related studies and a period from 2006-2020 for common MCDM methods.

3.3.3 Exclusion criteria

All other studies that are related to the other Distributed Ledger Technologies (DLT) were removed. The study focuses on studies related to the blockchain network and common multi-criteria decision-making algorithms.

3.4 Identify Research Gap

From the literature, the research problem is identified through reviewing, analyzing, and exploring existing studies. The problem statement is explained in the Introduction section of this research (refer to Section 2.7 and Section 2.7.1).

3.5 Development of a selection method for comparing and selecting blockchain platforms:

The selection method comprises three main stages for the comparison and selection of blockchain platforms. The selection criteria for comparing and evaluating blockchain platforms are identified by reviewing existing studies. A survey was conducted to evaluate the suitability of these criteria in blockchain platform selection by the blockchain practitioners. A selection method for comparing and selecting blockchain platforms to meet specific project needs was developed based on the integrated decision-making methods, Fuzzy AHP-TOPSIS and the shortlisted selection criteria. Section 3.5.1 discusses the reasons for adopting Fuzzy AHP-TOPSIS in the proposed selection method.

3.5.1 Why Fuzzy AHP-TOSIS method?

Many studies have compared different MCDM techniques based on their perspectives and theories (Velasquez & Hester, 2013; Jadhav & Sonar, 2009; Zaidan et al., 2015). Some MCDM techniques are used to solve ranking problems, such as the Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Elimination and Choice Expressing Reality (ELECTRE III), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) approaches (Araujo et al., 2018).

Analytic Hierarchy Process (AHP) is easy to use and scalable, however, due to interdependency between criteria and alternatives, it can lead to inconsistencies between judgment and ranking criteria (Velasquez & Hester, 2013). Moreover, AHP is a time-consuming technique as it involves mathematical calculations and a considerable number of pairwise comparisons (Zaidan et al., 2015). The fuzzy-based approach improves the decision-making process by solving the problem of the ambiguity and impreciseness of human judgments. However, computing fuzzy appropriateness index values and ranking values for all alternatives is difficult (Jadhav & Sonar, 2009).

Although TOPSIS is one of the most practical methods which helps identify the most suitable alternatives quickly, major drawbacks regarding TOPSIS are its inability to issue criteria weights and to perform consistency checks on judgements (Zaidan et al., 2015). ELECTRE takes uncertainty and vagueness into account, however, its process and outcome can be hard to explain nonprofessionally. PROMETHEE does not provide a clear method by which to assign weights. Data Envelopment Analysis (DEA) is not capable to deal with imprecise data as it assumes that all input and output are exactly known. (Velasquez & Hester, 2013).

The main weaknesses in WSM and HAW techniques are the arbitrary assignment of attributes weights and the difficulty in implementation when the number of criteria increases (Jadhav & Sonar, 2009; Zaidan et al., 2015). The disadvantage with SAW is, it does not always reflect the real situation as all the values of the criteria should be maximum and positive (Zaidan et al., 2015).

Referring to the comparison of studies that have applied MCDM techniques (Table 2.2), the authors usually used a combination of the AHP method with other MCDM techniques (Sharma et al., 2020; Kabassi et al., 2020; Kabassi et al., 2020; Serhani et al., 2018; Secundo et al., 2017; Sun et al., 2016; Zaidan et al., 2015; Zaidan et al., 2015; Minetola et al., 2015; Sun et al., 2014; Sun et al., 2006) in their proposed decision-making process in different application domains. However, to the best of our knowledge, this combination has never been used before in the blockchain platform domain.

The primary advantage of AHP is the proportional easiness it provides in handling multiple criteria in addition to its ability to deal with both qualitative and quantitative data. But the actual human thinking style cannot be reflected using the traditional AHP, therefore Saaty (2008) developed fuzzy AHP, a fuzzy extension of AHP, to help decision-makers with the imprecise information and uncertainty in the decision-making process (Sharma et al., 2020). A more detailed description of the fuzzy AHP method is explained and discussed in these studies (i.e., Secundo et al., 2017; Sharma et al., 2020; Minetola et al., 2015; Sun et al., 2014; Mulubrhan et al., 2014).

A fuzzy-based technique is practised if performance rating and criteria weights are imprecise. In a fuzzy multiple-criteria decision-making (FMCDM) problem, the fuzzy set theory provides the advantage to easily use linguistic terms for alternative evaluation. Therefore, fuzziness and obscurity of the human decision-making process are accommodated in a fuzzy-based approach (Jadhav & Sonar, 2009). Moreover, using the Fuzzy AHP method helps to remove the needless criterion on the condition that it is assigned an "absolutely not important" weight in comparison to other criteria by all decision-makers. Hence, the focus turns on more important criteria (Mulubrhan et al., 2014).

AHP can be used for weight calculation (Abdulateef et al., 2019; Velasquez & Hester, 2013) and TOPSIS is one of the most practical methods which helps identify the most suitable alternatives quickly (Zaidan et al., 2015). Hence 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. Furthermore, this combination has never been used before in the blockchain domain for the systematic selection of blockchain platforms.

3.6 Evaluate the accuracy and applicability of the proposed method:

Evaluation is the final step in the research methodology. After the steps of the proposed selection method is presented and explained in detail, the applicability of the respective method needs to be checked in terms of the accuracy and applicability to accommodate real-life project scenario. This will help improvise and enhance the proposed decision-making method. There are three evaluations carried out for this research. Three industry case studies at three software development companies are used to evaluate the accuracy of the proposed method. The second evaluation is to collect the opinions of blockchain practitioners to validate the suitability of the selection criteria and alternative blockchain platforms identified from existing studies in the selection of blockchain platforms. The third evaluation was conducted to collect experts' reviews on the applicability of the proposed method.

The evaluations aim to evaluate the accuracy of the outcome produced by the proposed method and the applicability of the proposed systematic selection method by two blockchain experts. The applicability check method proposed by Rosemann and Vessey (2008) was adopted to conduct the expert reviews. Moreover, limitations of the proposed method for comparison, evaluation, and selection of blockchain platforms were identified during the evaluation. Sections 3.6.1 to 3.6.3 explains each of the evaluations in more detail.

3.6.1 Case Study

The proposed selection method, FAT-BPSM is applied to three industry case studies at three software development companies to evaluate the accuracy. The steps for conducting case studies are:

Case Study Design:

For many kinds of software engineering research, a case study is a well-matched methodology, since contemporaneous objects of the study are difficult to study independently (Runeson and Höst, 2008) In this paper, the guidelines proposed by Runeson and Höst (2008) is adapted to design the case study. They have reported detailed guidelines and checklists for conducting software engineering case studies.

Case Selection:

Proper planning for conducting a case study is fundamental. To successfully conduct a case study, planning is necessary. Several issues need to be planned, for example, data collection methods, the places to be visited, documents to be read, persons to be interviewed, and the time of the interviews to be conducted, etc. (Runeson & Höst, 2009). The main objective of these case studies is to evaluate the accuracy of the proposed selection method, FAT-BPSM, for selecting the most appropriate blockchain platform based on project requirements.

Data Collection:

Lethbridge et al. (2005) described data collection as a vital step in any type of research study. They also outlined that vagueness or inaccuracy in this process can cause a severe impact on the entire study, leading to imprecise results. Elaboration is given on each case study scenario.

Applying FAT-BPSM to case studies:

The proposed selection method is applied to each case study which consists of three main stages for the comparison and selection of blockchain platforms: Pre-selection stage- Selection stage- and Final stage: Select the most appropriate blockchain platform.

3.6.2 Evaluation of the identified selection criteria and alternative blockchain platforms

A set of selection criteria and alternative blockchain platforms were identified from the existing studies as presented in Chapter 2 during the literature review. The objective of this evaluation is to validate whether the selection criteria and alternative blockchain platforms are suitable for the comparison and selection of blockchain platforms. The evaluation was conducted as a survey to get the opinions of blockchain practitioners on the suitability of the features and quality attributes identified as selection criteria for the evaluation and selection of blockchain platforms. Likewise, 30 more common blockchain platforms were shortlisted as potential alternatives in different application domains.

3.6.3 Applicability of the Fuzzy AHP-TOPSIS Blockchain Platform Selection Method (FAT-BPSM)

The objective of this evaluation is to evaluate the applicability of FAT-BPSM to effectively aid the selection of blockchain platforms based on user requirements by two blockchain experts. Rosemann & Vessey (2008) suggested conducting an applicability check on the concerned research object. They also argued that applicability checks allow practitioners to provide feedback on the research objects to the academic community. On top of that, applicability checks help improve the relevance of the conducted research over time as well as improving future research as a result of relating studies with theories or models' alterations (Rosemann & Vessey, 2008). Practical evaluations of the theories, models, frameworks, processes, technical artifacts, or other theoretically based information system artifacts that the academic community either uses or produces in its research can be referred to as applicability checks. The following steps are carried out for data collection and analysis:

- Step 1: Planning the applicability check
- Step 2: Selecting the person to conduct the check

- Step 3: Ensuring that participants are familiar with the research object under examination
- Step 4: Designing the materials for conducting the check
- Step 5: Establishing an appropriate environment for conducting the check
- Step 6: Conducting the check
- Step 7: Analyzing the data

3.7 Summary

This chapter discussed the research methodology for conducting this study. The research methodology, which consists of four (4) main steps. Each step and sub-step are discussed and justified to explain the process of conducting this research. The next chapter will discuss the proposed selection method for comparing and selecting blockchain platforms.

CHAPTER 4: PROPOSED WORK

In this chapter, In Section 4.1, Fuzzy AHP-TOPSIS Blockchain Platform Selection Method (FAT-BPSM) is explained and described with the details of each step proposed in this method for conducting the decision-making process of selection of the most appropriate blockchain platforms. Section 4.2 presents a summary of the chapter.

4.1. Fuzzy AHP-TOPSIS Blockchain Platform Selection Method (FAT-BPSM)

The Fuzzy AHP-TOPSIS Blockchain Platform Selection Method (FAT-BPSM) described here is intended to help decision-makers to choose a suitable blockchain platform based on their requirements. The method compares and evaluates the platform's features and quality attributes, and priorities are assigned to them according to the obtained weights. Figure 4.1 gives an overview of the FAT-BPSM.

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. After project decision-makers prioritized all the requirements, potential blockchain platforms will be shortlisted as possible solutions. The shortlisted Blockchain platforms will be the alternatives that will be compared and evaluated in the integrated Fuzzy AHP-TOPSIS decision-making process of the proposed selection method. In the end, the proposed method will identify the most appropriate blockchain platform which fits project needs, amongst the alternatives. Sections 4.1.1 to 4.1.3. explain each step of the proposed selection method in detail.

Mapping of platform information as the knowledge base

Information on mapping for the shortlisted features and quality attributes are collected based on documentation, official website, online resources, and white papers of 25 platforms. The following two mapping information contribute as the knowledge base to help decision-makers to refer to the features and quality attributes of each blockchain information to make a comparison and evaluation.

Mapping for blockchain quality attributes can be found on the following link:

https://drive.google.com/file/d/1MqNuq96-8vBNAPZKmJ8e5C8YN-28IZBb/view?usp=sharing

Mapping for blockchain features can be found on the following link:

https://drive.google.com/file/d/1N6v8VCguxSBNS1p3v2WCCkPRNafyyfxT/view?usp=sharing

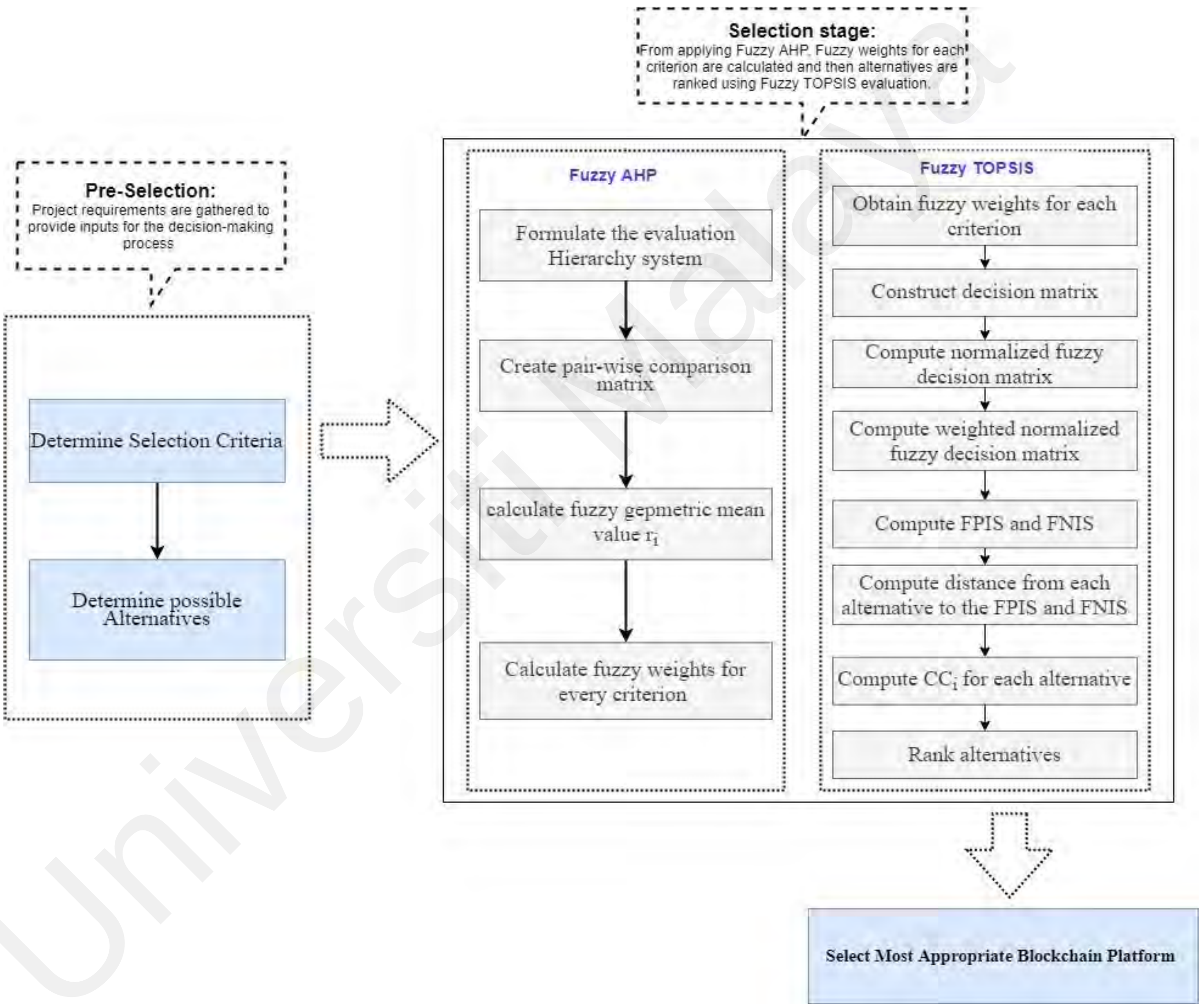

Figure 4.1 Overview of proposed FAT-BPSM

4.1.1 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 quality attributes for comparison and selection, feasible alternatives (blockchain platforms) matching the specified features and quality requirements. The following steps are performed in the pre-selection stage: (1) Determine selection criteria; (2) Determine possible alternatives.

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 quality attributes of blockchain platforms are derived from the existing studies.

Based on conducted literature review, blockchain platforms' evaluation criteria can be categorized into two (2) main categories, namely features and quality attributes. 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. Table 4.1 shows the list of shortlisted feature categories and criteria under each feature category. The detailed description of each feature and criterion can be referred to in Section 2.6 in Chapter 2.

Table 4.1 Shortlisted feature categories and criteria of each feature category

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

Features	Feature criteria
	* 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)

Table 4.1, continued

Features	Feature criteria
	* parallel block processing * new communication patterns
Data model	* UTXO * Account * UTXO+ * Key-value

Existing studies take some quality attribute measures into account to assess and select suitable blockchain platforms for their projects, applications or use cases. The quality attributes from System and Software Quality Models defined in ISO/IEC25010 are used to identify what are the main quality attributes that have been considered as evaluation criteria. ISO/IEC25010 consists of the Quality in use model (ISO, 2011) and Product quality model (ISO, 2011). Product Quality Model (ISO, 2011) consists of eight main quality attributes are Functional suitability, performance efficiency, compatibility, usability, reliability, security, maintainability, and portability. Quality in use model (ISO, 2011) comprising five main quality attributes which are effectiveness, efficiency, satisfaction, freedom from risk and context coverage. Domain-specific criteria not covered by ISO/IEC25010 are product, supplier, cost, size, and privacy. Table 4.2 shows the list of shortlisted quality attributes and the criteria of each quality attribute. Description of each quality criterion can be referred to in Section 2.6 in Chapter 2.

Table 4.2 Shortlisted Quality Attributes and 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

Table 4.2, continued

Quality Attribute	Quality Criteria
	* 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

In this step, decision-makers specify their blockchain criteria requirements using the requirements prioritization technique, Numerical Assignment Technique. This technique simplifies selection criteria analysis and prioritizes the requirements (Hudaib et al., 2018) to select the best-matching blockchain platform for a project. The numerical Assignment Technique works with classifying requirements into different groups. Although the number of groups is arbitrary, three group divisions; optional, standard, and critical, are more frequently used (Ma, 2009). Each project requirement can be assigned a numerical scale of 1 to 3 which indicates their level of importance (Hudaib et al., 2018) as follows:

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.

2) Rather important (standard): This means that the project would be nice if the requirements in this group are considered.

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.

In each of the groups, all requirements have equal priority, meaning that not any requirement have higher or lower priority from the other in the same group (Ma, 2009). Each prioritized criterion is then further put under the features or quality classifications. Table 4.3 illustrates a representation of how the ranking and classification can be done. 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.

Because numerical assignment technique groups the requirements only once, it causes low complexity with high speed. It is the most traditional and popular technique for prioritizing large size requirements and is very easy to use (Hudaib et al., 2018). The prioritized list of criteria is also expected to ease the process of decision-making using the Fuzzy AHP-TOPSIS approach of the proposed selection method.

Table 4.3 Requirements/criteria prioritization sample by decision-makers

		Feature	**Quality Attribute**
3	Very Important (critical)	1. Requirement 3 2. Requirement 5	3. Requirement 7
2	Rather Important (standard)	1. Requirement 4	2. Requirement 8 3. Requirement 9

Table 4.3, continued

1	Does not matter (optional)	1. Requirement 1 2. Requirement 2 3. Requirement 6

Step 2. Determine feasible alternatives.

According to the literature, 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 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

A prioritized list of selection criteria (features and quality attributes) is gathered from the previous step. Blockchain platforms with the supportability of selected "very important" features are shortlisted as possible alternatives in this study. Additionally, blockchain platforms that have temporarily unavailable or incomplete documentation (e.g., Chain, Eris) were excluded as potential alternatives as well.

4.1.2 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. A selection method based on Fuzzy AHP-TOPSIS is formulated for the blockchain platform selection problem. This structured integrated method, FAT-BPSM comprises 12 steps that are required for the comparison and selection of a blockchain platform according.

Steps 1 to Step 4 are derived from Fuzzy AHP:

Step 1: Formulate the evaluation hierarchy system using prioritized features and quality attributes and shortlisted platforms 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.

Step 2: Create a pair-wise comparison matrix with the help of a scale of relative importance. In this step, decision-makers compare one criterion with respect to other criteria using linguistic terms. Fuzzification refers to the process of converting linguistic terms into membership function (Triangular membership function).

$$\mu_{\tilde{A}}(x) = \tilde{A} = (l, m, u)$$

Fuzzy number

The scale of relative importance with crisp numeric values and their corresponding fuzzy numbers is shown in Table 4.4 Each Fuzzy scale has three values, namely, the lowest value (lower, l), middle value (median, m), and the highest value (upper, u).

Table 4.4 Linguistic terms and the corresponding triangular fuzzy numbers

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)

Note. The linguistic terms are adapted from Soberi and Ahmad (2016)

The reciprocal value can be converted into a fuzzy number using this equation:

$$\tilde{A}^{-1} = (l, m, u)^{-1} = (\frac{1}{u}.\frac{1}{m},\frac{1}{l})$$

Subsequently, a Fuzzified pair-wise comparison matrix is constructed. In this paper, Fuzzy AHP proposed by Buckley (1985) is used to calculate the weights using geometric mean.

Step 3: Calculate fuzzy geometric mean value r_i using this formula:

$$r_i = \left(a_{ij}^{1} \times a_{ij}^{2} \cdots a_{ij}^{10}\right)^{1/10}$$

To multiply two fuzzy numbers the following equation can be used:

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

Step 4: Calculate fuzzy weights for every criterion using this formula:

$$w_i = r_i \times (r_1 + r_2 + r_3 + \cdots + r_n)^{-1}$$

The equation that can be used to add two fuzzy numbers is as follows:

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

Steps 5 to Step 12 are derived from Fuzzy TOPSIS:

Step 5: From applying Fuzzy AHP, fuzzy weights for each criterion are obtained. These values are collected to proceed with the Fuzzy TOPSIS evaluation.

Step 6: Fuzzy decision matrix is made using the judgmental values from decision-makers based on the mapping for quality attributes for each shortlisted alternative. Table 4.5 illustrates the linguistic terms for rating the alternatives and their related fuzzy values as used by Nădăban et al. (2016).

Table 4.5 Linguistic terms for alternative ratings

Linguistic terms for alternative ratings	Triangular FN
Very good	(9,10,10)
good	(7,9,10)
Medium	(3,5,7)
Poor	(1,3,5)
Very poor	(1,1,3)

Step 7: Compute normalized fuzzy decision matrix. Benefit criteria are those criteria in which maximum values are desired while non-beneficial (cost) criteria are the ones in which minimum values are desired.

$$r_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \; and \; c_j^* = {}^{max}{}_j(c_{ij}) \; (benefit\ criteria)$$

$$r_{ij} = \left(\frac{a_j^-}{c_{ij}}, \; \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \; and \; a_j^- = {}^{min}{}_j(a_{ij})(cost\ criteria)$$

Step 8: Compute weighted normalized fuzzy decision matrix:

$$v_{ij} = r_{ij} \times w_j$$

On solving we will get a matrix knows as the weighted normalized fuzzy decision matrix.

Step 9: Compute Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS).

$$FPIS\ A^* = (v_1^*, v_2^*, \cdots, v_n^*)\ where\ v_j^* = {}^{max}_{\ \ i}(v_{ij3})$$

$$FNIS\ A^- = (v_1^-, v_2^-, \cdots, v_n^-)\ where\ v_j^- = {}^{min}_{\ \ i}(v_{ij1})$$

Step 10: Compute the distance from each alternative to the FPIS and to the FNIS:

d (x, y) is the distance between the two fuzzy numbers x and y.

$$d(x,y) = \sqrt{\frac{1}{3}[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]}$$

$$D_i^* = \sum_{j=1}^{n} d\left(v_{ij}, v_j^*\right)$$

$$D_i^- = \sum_{j=1}^{n} d\left(v_{ij}, v_j^-\right)$$

Step 11: Compute the closeness coefficient CCi for each alternative:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}$$

Step 12: **Rank the alternatives**

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

4.1.3 Final stage: Select the most appropriate blockchain platform

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 previous step 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 is considered as the most appropriate blockchain platform, fitting the project requirements and alternative with the lowest value will be the least appropriate blockchain platform. The alternative which ranked as number 1 is recommended as the most appropriate blockchain platform for the project.

4.2 Summary

This chapter describes the systematic selection method proposed in this research to compare, evaluate, and select blockchain platforms. FAT-BPSM comprises three main stages: (1) Pre-Selection, (2) Selection stage, and (3) Final Stage: Select the most appropriate blockchain platform. Each stage was explained in detail. The next chapter will discuss the evaluations conducted to evaluate the identified set of selection criteria, alternative blockchain platforms and the proposed method.

CHAPTER 5: EVALUATION

5.1 Introduction

This chapter discusses the evaluations conducted to evaluate the accuracy and applicability of the proposed selection method, Fuzzy AHP-TOPSIS Blockchain Platform Selection Method (FAT-BPSM). Section 5.2 presents three cases used to prove the accuracy of the FAT-BPSM. Section 5.3 explains the evaluation of the identified selection criteria and alternative blockchain platforms. Section 5.4 describes the applicability of the proposed method using expert reviews. This chapter ends with the summary section to conclude the evaluation (Section 5.5).

5.2 Case Study

Three case studies are conducted to evaluate the accuracy of the proposed selection method, FAT-BPSM. Section 5.2.1 outlines the case study design. Section 5.2.2 explains the case selection. Section 5.2.3 describes the data source and methods used to collect data. Section 5.2.4 describes the implication of FAT-BPSM to three industry case studies at three software development companies. Section 5.2.5 presents the results and data analysis. Section 5.2.6 discusses the results.

5.2.1 Case Study Design

The adapted procedure to conduct the case study is illustrated in Figure 5.1. Generally, complexities or issues in a particular research domain can be tackled and improved by analyzing practical events. Pertaining to this research, the proposed method was implemented in three cases to evaluate the accuracy of the proposed method for the blockchain platform selection problem.

Figure 5.1 Case study procedure to evaluate the FAT-BPSM

As illustrated in Figure 5.1, the case study begins with selecting a domain and real-world project context 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 three cases and the results were analyzed to conclude if the proposed selection method has fulfilled its ultimate objectives. The upcoming subsections precisely elaborate the tasks under each procedure, as shown in Figure 5.1.

5.2.2 Case Selection

Three case studies adapted from the existing study, P16 (Farshidi et al., 2020) which initially was conducted at three software development companies to evaluate and signify the usefulness and effectiveness of their decision support system (DSS). The three industrial cases were selected from P16 in this evaluation since they are addressing multi-criteria decision-making problems related to the selection of blockchain platforms. In P16, case-study participants were asked to employ the DSS to analyze, document, track, and prioritize their blockchain feature requirements. To evaluate the accuracy of the proposed FAT-BPSM, the method was applied to these three industrial case studies to select blockchain platforms for these three projects. The platforms selected by FAT-BPSM was compared with the platforms selected by the DSS proposed by Farshidi et al. (2020). The remaining sections describe the case studies and discuss the results of the case studies.

5.2.3 Data Collection

In this subsection, elaboration has been given on each case study scenario (company description and their prioritized requirements). The information of each case study was extracted from P16.

A. Case Study 1: ShareCompany BIQH

ShareCompany BIQH, a FinTech company in the Netherlands, supports two well-known Dutch banks with accommodating the requirements put forth by the European Union regarding packaged retail investment and insurance-based products (PRIIP/KID regulation). ShareCompany BIQH is now interested in investigating the possibility of deploying its current centralized financial system on a blockchain platform.

B. Case Study 2: DUO

DUO is the administrative and executive agency of the Dutch government for managing the educational system. DUO operates in the name of the Ministry of Education, Culture, and Science and the Ministry of Social Affairs and Employment. DUO has eight different main functions, with several activities as their core focus. This case study will merely focus on the process of student financing in the form of granting loans. DUO is interested in building a decentralized application based on blockchain technology to address the requirements of student financing activities.

C. Case Study 3: Veris Foundation

The Veris Foundation is an organization focusing on the American healthcare system. The Veris Foundation addresses the problem of bringing healthcare service providers, insurers, and banks together to authorize the provisioning and payment for healthcare services. The Foundation is a nonprofit entity whose core objective is the establishment of a platform to reduce the cost of healthcare and make it more affordable to patients. Traditional, centralized healthcare systems are slow, redundant, and expensive because service providers and payers employ their staff and separate software stacks to facilitate their medical claims processes. These isolated systems make the sharing of necessary information complicated, costly, and prone to errors and fraud. The Veris Foundation is interested in finding the best fitting blockchain platform, as they believe that creating decentralized databases enables all parties to securely access and share data within and across organizations, eliminating the need to hire and maintain expensive third-party information systems.

Table 5.2.1 summarizes the requirements and corresponding blockchain feature requirements that were stated by the DSS case-study participants with their assigned priorities according to MoSCoW**.** In the study conducted by Farshidi et al (2020), MoSCoW method (Ma, 2009) was applied by project decision-makers to prioritize requirements into four priority groups: "MUST have", "SHOULD have", "COULD have", and "WON'T have". According to the definition, "COULD have" defines the requirements which are preferred but are not necessary and "WON'T have" defines requirements that can be postponed and suggested for future execution.

It is important to mention that when applying FAT-BPSM, those criteria which are not shortlisted will be excluded from the decision-making process. For Case Study 1, Federated Byzantine Fault Tolerance is considered as Federated Byzantine Agreement (FBA). Because "Byzantine Agreement is Byzantine fault tolerance of distributed computing systems that enable them to come to a consensus despite arbitrary behavior from a fraction of the nodes in the network" (Curran, B. (2018, November 2). What is The Stellar Consensus Protocol? Complete Beginner's Guide. BLOCKONOMI. https://blockonomi.com/stellar-consensus-protocol/). Innovation (Case Study 2) and Share-like token (Case Study 3) are removed from the requirement because they are not included in the shortlisted features of this research.

Table 5.1 Blockchain feature requirements of the three industry case studies

MoSCoW	ShareCompany BIQH	DUO	Veris Foundation
Must-Have	1. Permissioned platform 2. Interoperability technologies 3. Smart Contract 4. Java 5. Sybil-attack resistant 6. Privacy technologies 7. Enterprise system integration 8. Network Layer 9. Application Layer	1. Protocol Layer 2. Network Layer 3. Application Layer 4. Smart Contract 5. On-chain transactions 6. Cryptographic Tokens 7. Sybil attack resistant 8. Spam-attack resistant	1. Permissioned Blockchain 2. Smart Contract 3. Cryptographic Token 4. Protocol Layer 5. Network Layer 6. Application Layer 7. Interoperability technologies

MoSCoW	ShareCompany BIQH	DUO	Veris Foundation
	10. Protocol Layer		8. Enterprise system integration 9. On-chain transactions
Should-Have	1. Golang 2. Private Platform 3. JavaScript 4. Resilience technologies 5. Instant Transaction Finality 6. High Transaction Speed 7. Zero-knowledge Proof 8. High Maturity 9. High Popularity	1. Turing-complete 2. JavaScript 3. High Maturity 4. Native token 5. Cryptocurrency (purpose) 6. Solidity	1. Private Blockchain 2. Delegated Byzantine Fault Tolerance (dBFT) 3. Delegated Proof-of-Stake (DPoS) 4. Share-like token 5. Network token 6. Network value token 7. Work token 8. Usage token
Could-Have	1. zK-SNARKS 2. Spam-attack resistant 3. Virtual Machine 4. Turing-complete 5. On-chain transactions 6. Practical Byzantine Fault Tolerance (pBFT) 7. Federated Byzantine Fault Tolerance 8. Delegated Byzantine Fault Tolerance (dBFT)	1. Proof-of-Work (PoW) 2. Proof-of-Stake (PoS) 3. Delegated Proof-of-Stake (DPoS) 4. Practical Byzantine Fault Tolerance (pBFT) 5. Federated Byzantine Agreement (FBA) 6. Delegated Byzantine Fault Tolerance (dBFT) 7. Proof-of-Authority (PoA) 8. Proof-of-Elapsed Time (POET) 9. Public Platform 10. Private Platform 11. Permissioned Platform 12. Permissionless Platform 13. Virtual Machine 14. Java 15. C++ 16. Zero-knowledge Proof	1. Privacy Technologies 2. Virtual Machine 3. Turing Complete

Table 5.1, continued

MoSCoW	ShareCompany BIQH	DUO	Veris Foundation
		17. Zk-SNARKS 18. Hard-fork resistant 19. Quantum resistant 20. Instant transaction finality 21. Medium Popularity 22. Medium Innovation 23. High Transaction speed	
Will not have	1. Proof-of-Work 2. Proof-of-Stake 3. Directed Acyclic Graph	Directed Acyclic Graph	(None)

Note: The requirements were adapted from P16 (Farshidi et al., 2020)

5.2.4 Applying FAT-BPSM to case studies

Pre-selection stage

Step 1. The importance of selection criteria was ranked according to three prioritization levels of the Numerical Assignment Technique. The prioritization of requirements of each case study is shown in Table 5.2, Table 5.2, and Table 5.3. In FAT-BPSM, Numerical Assignment Technique was adopted for prioritization of selection criteria instead of using MoSCoW. As a result, these two groups (i.e., "COULD have" and "WON'T have") in MoSCoW are combined since it is believed that the requirements in these two groups have the same level of priority. Moreover, decision-makers often ignore what does not matter to them and focus more on what they want. Based on requirements collected (see Table 5.1), **29 criteria** were determined selection criteria for Case Study 1: ShareCompany BIQH, (see Table 5.2), **36 criteria** were determined as selection criteria for Case Study 2: DUO (see Table 5.3), **19 criteria** were determined as selection criteria for Case Study 3: Veris Foundation (see Table 5.4).

Table 5.2 Prioritized requirements for ShareCompany BIQH

Level	Priority	Feature	Quality Attribute
3	Very Important (critical)	1. Permissioned platform 2. Smart Contract 3. Java 4. Sybil-attack resistant 5. Privacy technologies 6. Enterprise system integration 7. Network Layer 8. Application Layer 9. Protocol Layer	10. Interoperability
2	Rather Important (standard)	1. Golang 2. Private Platform 3. JavaScript 4. Resilience technologies 5. Instant Transaction Finality 6. Zero-knowledge Proof	7. High Transaction Speed 8. High Maturity 9. High Popularity
1	Does not matter (optional)	1. zK-SNARKS 2. Spam-attack resistant 3. Virtual Machine 4. Turing-complete 5. On-chain transactions 6. Practical Byzantine Fault Tolerance (pBFT) 7. Federated Byzantine Fault Tolerance (Federated byzantine agreement (FBA)) 8. Delegated Byzantine Fault Tolerance (dBFT) 9. Proof-of-Work (PoW) 10. Proof-of-Stake (PoS)	

Table 5.3 prioritized requirements for DUO

Level	Priority	Feature	Quality Attribute
3	Very Important (critical)	1. Protocol Layer 2. Network Layer 3. Application Layer 4. Smart Contract 5. On-chain transactions 6. Cryptographic Tokens 7. Sybil attacks resistant	

Level	Priority	Feature	Quality Attribute
		8. Spam-attack resistant	
2	Rather Important (standard)	1. Turing-complete 2. JavaScript 3. Native token 4. Cryptocurrency (purpose) 5. Solidity	6. Maturity
1	Does not matter (optional)	1. Proof-of-Work (PoW) 2. Proof-of-Stake (PoS) 3. Delegated Proof-of-Stake (DPoS) 4. Practical Byzantine Fault Tolerance (pBFT) 5. Federated Byzantine Agreement (FBA) 6. Delegated Byzantine Fault Tolerance (dBFT) 7. Proof-of-Authority (PoA) 8. Proof-of-Elapsed Time (POET) 9. Public Platform 10. Private Platform 11. Permissioned Platform 12. Permissionless Platform 13. Virtual Machine 14. Java 15. C++ 16. Zero-knowledge Proof 17. Zk-SNARKS 18. Hard-fork resistant 19. Quantum resistant 20. Instant transaction finality	21. Popularity 22. Transaction speed

Table 5.4 prioritized requirements for Veris Foundation

Level	Priority	Feature	Quality Attribute
3	Very Important (critical)	1. Permissioned Blockchain 2. Smart Contract 3. Cryptographic Token 4. Protocol Layer 5. Network Layer 6. Application Layer 7. Enterprise system integration 8. On-chain transactions	9. Interoperability

Level	Priority	Feature	Quality Attribute
2	Rather Important (standard)	1. Private Blockchain 2. Delegated Byzantine Fault Tolerance (dBFT) 3. Delegated Proof-of-Stake (DPoS) 4. Network token 5. Network value token 6. Work token 7. Usage token	
1	Does not matter (optional)	1. Privacy Technologies 2. Virtual Machine 3. Turing Complete	

Step 2. Determine feasible alternatives.

In this step, feature requirements that are prioritized as very important are mapped with the shortlisted blockchain platform and those platforms which met all the very important requirements were selected as the feasible alternatives. For example, based on Table 5.2, the following features are prioritized as critical for **ShareCompany BIQH** and have been used to shortlist the feasible alternatives for Case Study 1:

1. Permissioned platform
2. Smart Contract
3. Java
4. Sybil-attack resistant
5. Privacy technologies
6. Enterprise system integration
7. Network Layer
8. Application Layer
9. Protocol Layer

The same step was applied to Case Study 2 and Case Study 3 to get the feasible alternatives. According to the mapping of very important (critical) features and platforms, the feasible alternative blockchain platforms shortlisted for each case study are as follows:

- Four feasible alternatives shortlisted for **Case Study 1: ShareCompany BIQH** are Ethereum, R3 Corda, JPMorgan Quorum and Hyperledger Fabric

- Seven feasible alternatives shortlisted for **Case Study 2: DUO** is Ethereum, Hyperledger Fabric, Hyperledger Sawtooth, NEO, Stellar, Waves Platform, and Komodo.
- Five feasible alternatives shortlisted for **Veris Foundation** are Ethereum, Hyperledger Fabric, Hyperledger Sawtooth, NEO, and Stellar.

Selection stage:

Steps 1 to Step 4 are derived from Fuzzy AHP:

Step 1. Formulate an evaluation hierarchy system. The hierarchy is composed of different levels, from the objective, through varieties of criteria to a set of alternatives. Evaluation criteria and feasible alternatives, and the overall goal, which is to select the most appropriate blockchain platform, all indicate separate levels of the hierarchy. The constructed hierarchy for each of the case studies is shown in Figure 5.2 to Figure 5.4.

Step 2: Create a pairwise comparison matrix

Decision-makers possess rich experience regarding the working culture of the organization, the inputs are gathered in terms of linguistic variables for the selected criteria based on the prioritization in Step 1. Excerpt of pairwise comparison among all the criteria by comparing the criteria to each other using the fuzzy scale of relative importance and a pairwise comparison matrix for **ShareCompany BIQH (Case Study 1)** are shown in Table 5.5 and Table 5.6. Complete pairwise comparison matrix tables and all calculations for each case study can be referred to in the following links:

ShareCompany BIQH (Case study 1) Excel file in Google Drive:
https://drive.google.com/file/d/1L9fBf23FpPRImtmChgx8D1IyEJiHnlTu/view?usp=sharing

DUO (Case study 2) Excel file in Google Drive:

https://drive.google.com/file/d/1Fdq7pBDogZqk5E5cHYVJgnFLS2GXbEKy/view?usp=sharing

Veris Foundation (Case study 3) Excel file in Google Drive:

https://drive.google.com/file/d/1KGczdCPFqQDvgv-LTNqdYFn-bMeU7E0A/view?usp=sharing

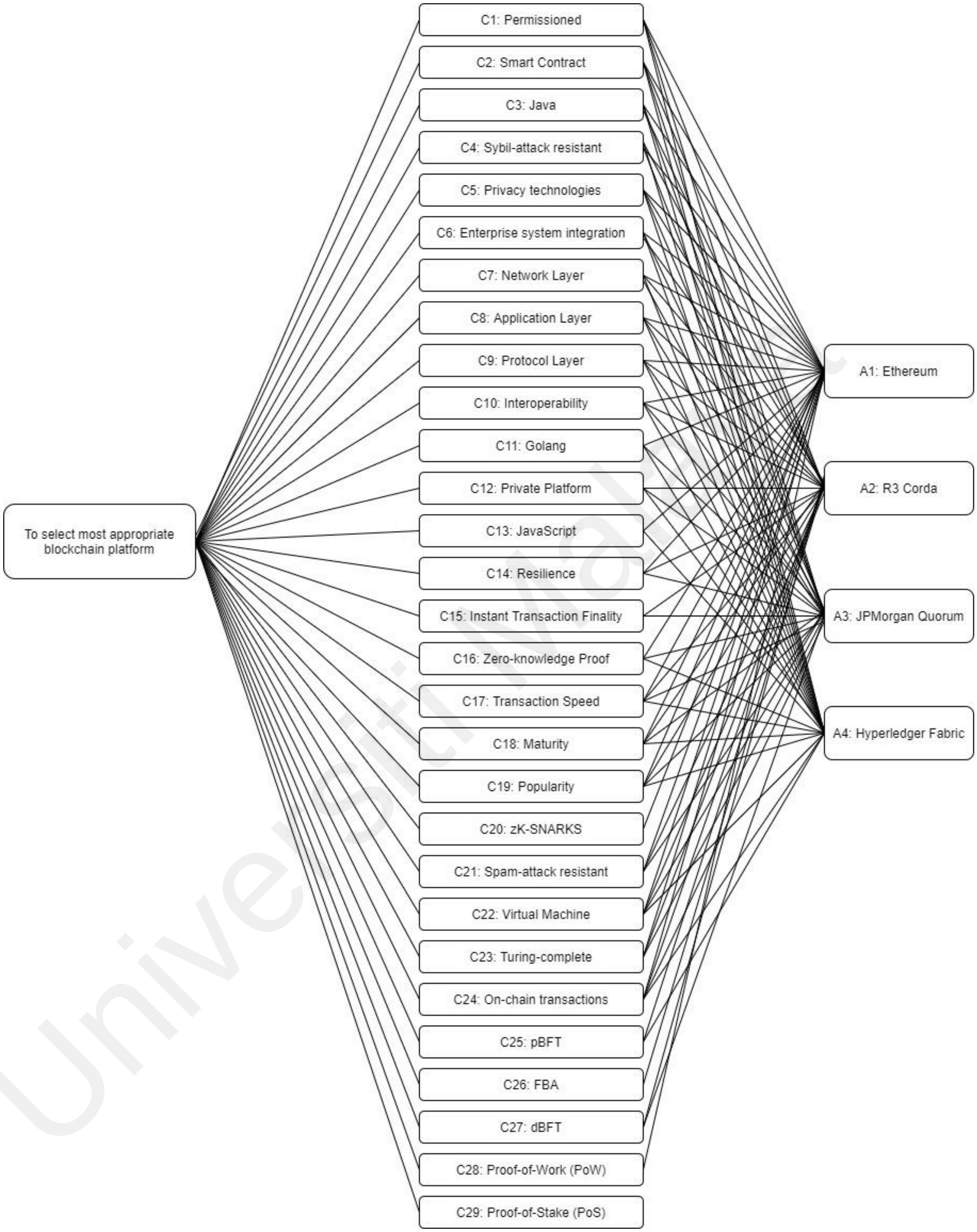

Figure 5.2 Evaluation Hierarchy system for ShareCompany BIQH

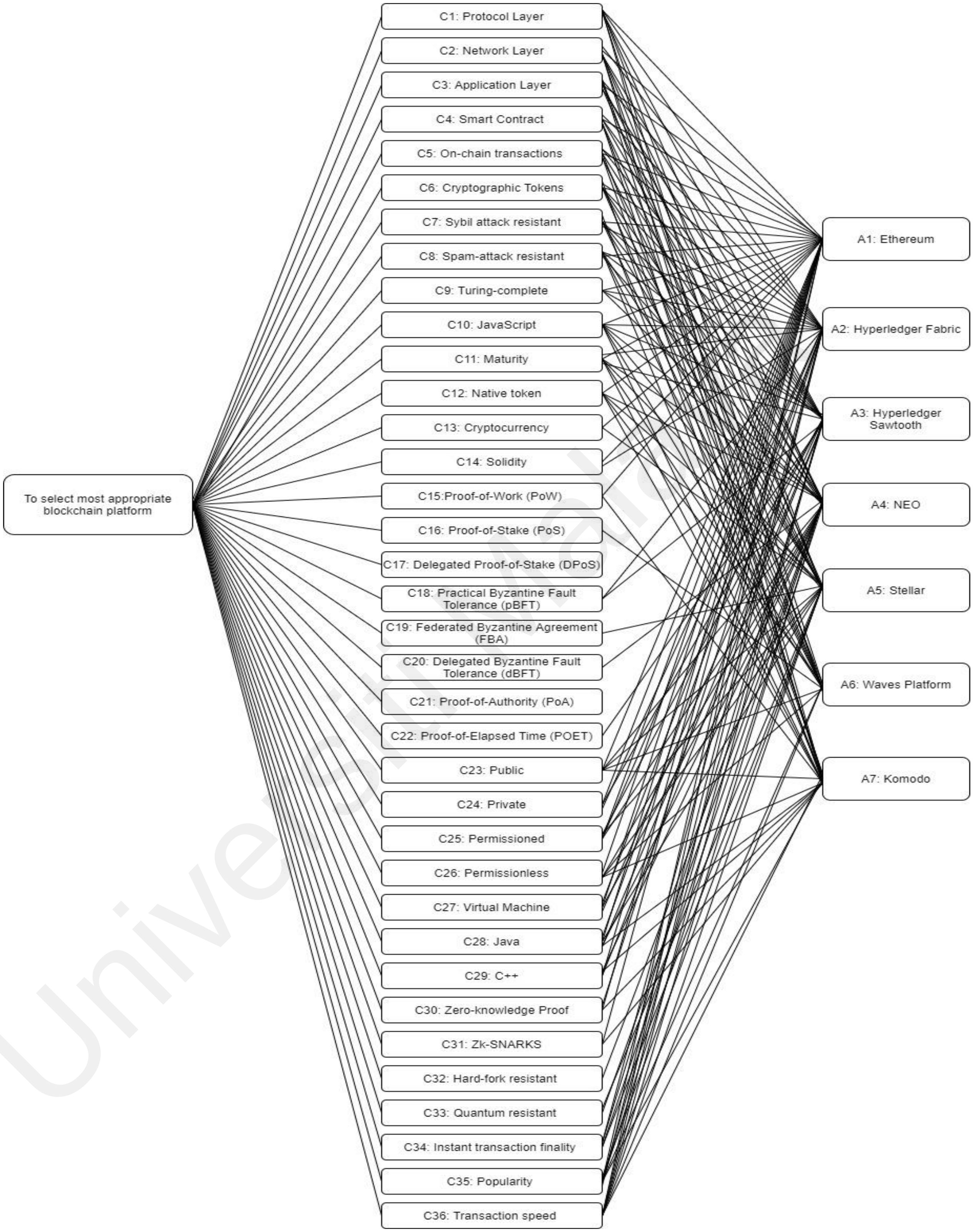

Figure 5.3 Evaluation Hierarchy system for DUO

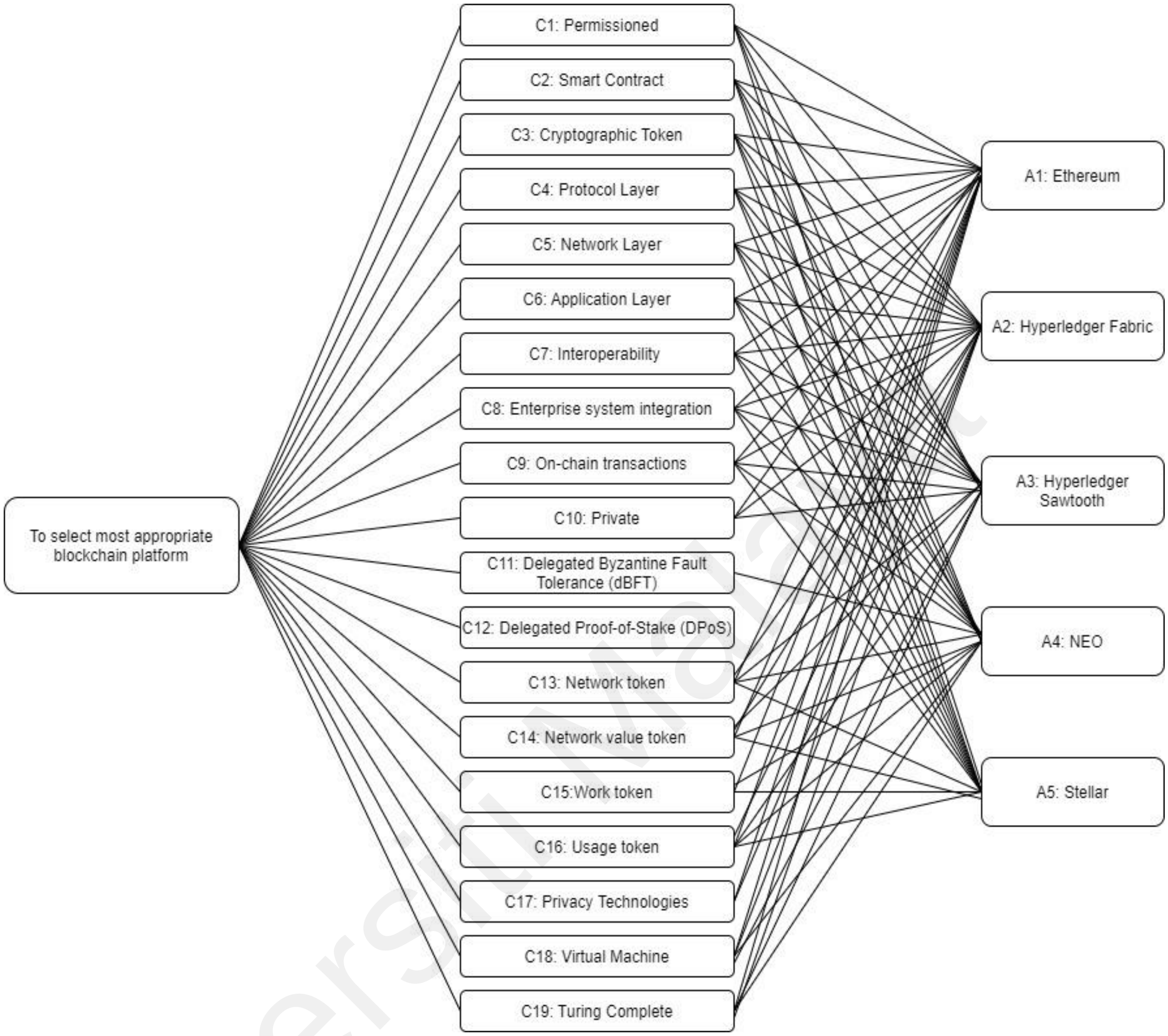

Figure 5.4 Evaluation Hierarchy system for Veris Foundation

Table 5.5 Excerpt of Pairwise comparison among all the criteria for ShareCompany BIQH

Q#	A. Imp (9,9,9)	S. Imp (6,7,8)	F. Imp (4,5,6)	W.Imp (2,3,4)	CRITERIA	Eq. Imp (1,1,1)	CRITERIA	W.Imp (2,3,4)	F. Imp (4,5,6)	S. Imp (6,7,8)	A. Imp (9,9,9)
1					C1		C2				
2					C1		C3				
3					C1		C4				
4					C1		C5				
5					C1		C6				
6					C1		C7				
7					C1		C8				
8					C1		C9				
9					C1		C10				
10					C1		C11				
11					C1		C12				
12					C1		C13				
13					C1		C14				
14					C1		C15				
15					C1		C16				
16					C1		C17				
17					C1		C18				
18					C1		C19				
19					C1		C20				
20					C1		C21				
21					C1		C22				
22					C1		C23				
23					C1		C24				
24					C1		C25				
25					C1		C26				
26					C1		C27				
27					C1		C28				
28					C1		C29				
29					C2		C3				
30					C2		C4				
31					C2		C5				
32					C2		C6				
33					C2		C7				
34					C2		C8				
35					C2		C9				
36					C2		C10				
37					C2		C11				
38					C2		C12				
39					C2		C13				
40					C2		C14				
41					C2		C15				
42					C2		C16				
43					C2		C17				

Table 5.6 Excerpt of pair-wise comparison matrix for ShareCompany BIQH

CRI	C1			C2			C3			C4		
C1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
C2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
C3	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
C4	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
C5	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
C6	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
C7	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
C8	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
C9	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
C10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
C11	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250
C12	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250
C13	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250
C14	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250
C15	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250
C16	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250
C17	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250
C18	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250
C19	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250	0.167	0.200	0.250
C20	0.125	0.143	0.167	0.125	0.143	0.167	0.125	0.143	0.167	0.125	0.143	0.167
C21	0.125	0.143	0.167	0.125	0.143	0.167	0.125	0.143	0.167	0.125	0.143	0.167

Step 3: Calculate fuzzy geometric mean value r_i

In this step, the geometric means of fuzzy comparison value r_i were calculated as shown in Table 5.7 to Table 5.9. For example, the calculation for '**Criteria 1 in ShareCompany BIQH**' is calculated as:

$$r_i = \left(a_{ij}^1 \times a_{ij}^2 \cdots a_{ij}^{10}\right)^{1/10}$$

$= [(1*1*1*1*1*1*1*1*1*1*4*4*4*4*4*4*4*4*4*6*6*6*6*6*6*6*6*9*9)^{1/29};$
$(1*1*1*1*1*1*1*1*1*1*5*5*5*5*5*5*5*5*5*7*7*7*7*7*7*7*7*9*9)^{1/29};$
$(1*1*1*1*1*1*1*1*1*1*6*6*6*6*6*6*6*6*6*8*8*8*8*8*8*8*8*9*9)^{1/29]}$

= [2.933; 3.280; 3.601]

Table 5.7 Fuzzy geometric mean for ShareCompany BIQH

Criteria	r_i		
C1	2.933	3.280	3.601
C2	2.933	3.280	3.601
C3	2.933	3.280	3.601
C4	2.933	3.280	3.601
C5	2.933	3.280	3.601
C6	2.933	3.280	3.601
C7	2.933	3.280	3.601
C8	2.933	3.280	3.601
C9	2.933	3.280	3.601
C10	2.933	3.280	3.601
C11	0.894	1.023	1.173
C12	0.894	1.023	1.173
C13	0.894	1.023	1.173
C14	0.894	1.023	1.173
C15	0.894	1.023	1.173
C16	0.894	1.023	1.173
C17	0.894	1.023	1.173
C18	0.894	1.023	1.173
C19	0.894	1.023	1.173
C20	0.254	0.288	0.334
C21	0.254	0.288	0.334
C22	0.254	0.288	0.334
C23	0.254	0.288	0.334
C24	0.254	0.288	0.334
C25	0.254	0.288	0.334
C26	0.254	0.288	0.334
C27	0.254	0.288	0.334
C28	0.298	0.347	0.394
C29	0.298	0.347	0.394
Total	**40.009**	**45.005**	**50.031**

Table 5.8 Fuzzy geometric mean for DUO

Criteria	r_i		
C1	3.583	4.295	4.804
C2	3.583	4.295	4.804
C3	3.583	4.295	4.804
C4	3.583	4.295	4.804
C5	3.583	4.295	4.804
C6	3.583	4.295	4.804
C7	3.583	4.295	4.804
C8	3.583	4.295	4.804
C9	1.508	1.870	2.197
C10	1.508	1.870	2.197
C11	1.508	1.870	2.197
C12	1.508	1.870	2.197
C13	1.508	1.870	2.197
C14	1.508	1.870	2.197
C15	0.467	0.496	0.533
C16	0.467	0.496	0.533
C17	0.467	0.496	0.533
C18	0.467	0.496	0.533
C19	0.467	0.496	0.533
C20	0.467	0.496	0.533
C21	0.467	0.496	0.533
C22	0.467	0.496	0.533
C23	0.467	0.496	0.533
C24	0.467	0.496	0.533
C25	0.467	0.496	0.533
C26	0.467	0.496	0.533
C27	0.467	0.496	0.533
C28	0.467	0.496	0.533
C29	0.467	0.496	0.533
C30	0.467	0.496	0.533
C31	0.467	0.496	0.533
C32	0.467	0.496	0.533
C33	0.467	0.496	0.533
C34	0.467	0.496	0.533
C35	0.467	0.496	0.533
C36	0.467	0.496	0.533
Total	**47.992**	**56.496**	**63.336**

Table 5.9 Fuzzy geometric mean for Veris Foundation

Criteria	r_i		
C1	2.211	2.460	2.687
C2	2.211	2.460	2.687
C3	2.211	2.460	2.687
C4	2.211	2.460	2.687
C5	2.211	2.460	2.687
C6	2.211	2.460	2.687
C7	2.211	2.460	2.687
C8	2.211	2.460	2.687
C9	2.211	2.460	2.687
C10	0.533	0.602	0.688
C11	0.533	0.602	0.688
C12	0.533	0.602	0.688
C13	0.533	0.602	0.688
C14	0.533	0.602	0.688
C15	0.533	0.602	0.688
C16	0.533	0.602	0.688
C17	0.193	0.220	0.257
C18	0.193	0.220	0.257
C19	0.193	0.220	0.257
Total	**24.211**	**27.011**	**29.771**

Step 4: calculate Fuzzy weights for every criterion.

The geometric means of fuzzy values were then converted to fuzzy weights as shown in Table 5.10 to Table 5.12 by multiplying them with the reciprocal of the fuzzy geometric mean summation as following example calculation:

$$w_i = r_i \times (r_1 + r_2 + r_3 + \cdots + r_n)^{-1}$$

Reciprocal of fuzzy geometric mean summation for ShareCompany BIQH: (0.020, 0.022, 0.025)

= [(2.933*0.020); (3.280*0.022); (3.601*0.025)] = [0.059; 0.072; 0.090]

Table 5.10 Fuzzy weights for every criterion of ShareCompany BIQH

Criteria	W_i		
C1	0.059	0.072	0.090
C2	0.059	0.072	0.090
C3	0.059	0.072	0.090
C4	0.059	0.072	0.090
C5	0.059	0.072	0.090
C6	0.059	0.072	0.090
C7	0.059	0.072	0.090
C8	0.059	0.072	0.090
C9	0.059	0.072	0.090
C10	0.059	0.072	0.090
C11	0.018	0.023	0.029
C12	0.018	0.023	0.029
C13	0.018	0.023	0.029
C14	0.018	0.023	0.029
C15	0.018	0.023	0.029
C16	0.018	0.023	0.029
C17	0.018	0.023	0.029
C18	0.018	0.023	0.029
C19	0.018	0.023	0.029
C20	0.005	0.006	0.008
C21	0.005	0.006	0.008
C22	0.005	0.006	0.008
C23	0.005	0.006	0.008
C24	0.005	0.006	0.008
C25	0.005	0.006	0.008
C26	0.005	0.006	0.008
C27	0.005	0.006	0.008
C28	0.006	0.008	0.010
C29	0.006	0.008	0.010

Table 5.11 Fuzzy weights for every criterion of DUO

Criteria	W_i		
C1	0.057	0.077	0.101
C2	0.057	0.077	0.101
C3	0.057	0.077	0.101
C4	0.057	0.077	0.101
C5	0.057	0.077	0.101
C6	0.057	0.077	0.101
C7	0.057	0.077	0.101
C8	0.057	0.077	0.101
C9	0.024	0.034	0.046
C10	0.024	0.034	0.046
C11	0.024	0.034	0.046
C12	0.024	0.034	0.046
C13	0.024	0.034	0.046
C14	0.024	0.034	0.046
C15	0.007	0.009	0.011
C16	0.007	0.009	0.011
C17	0.007	0.009	0.011
C18	0.007	0.009	0.011
C19	0.007	0.009	0.011
C20	0.007	0.009	0.011
C21	0.007	0.009	0.011
C22	0.007	0.009	0.011
C23	0.007	0.009	0.011
C24	0.007	0.009	0.011
C25	0.007	0.009	0.011
C26	0.007	0.009	0.011
C27	0.007	0.009	0.011
C28	0.007	0.009	0.011
C29	0.007	0.009	0.011
C30	0.007	0.009	0.011
C31	0.007	0.009	0.011
C32	0.007	0.009	0.011
C33	0.007	0.009	0.011
C34	0.007	0.009	0.011
C35	0.007	0.009	0.011
C36	0.007	0.009	0.011

Table 5.12 Fuzzy weights for every criterion of Veris Foundation

Criteria	W_i		
C1	0.075	0.091	0.110
C2	0.075	0.091	0.110
C3	0.075	0.091	0.110
C4	0.075	0.091	0.110
C5	0.075	0.091	0.110
C6	0.075	0.091	0.110
C7	0.075	0.091	0.110
C8	0.075	0.091	0.110
C9	0.075	0.091	0.110
C10	0.018	0.022	0.028
C11	0.018	0.022	0.028
C12	0.018	0.022	0.028
C13	0.018	0.022	0.028
C14	0.018	0.022	0.028
C15	0.018	0.022	0.028
C16	0.018	0.022	0.028
C17	0.007	0.008	0.011
C18	0.007	0.008	0.011
C19	0.007	0.008	0.011

Steps 5 to Step 12 are derived from Fuzzy TOPSIS:

Step 5: Fuzzy weights for each criterion is obtained from applying Fuzzy AHP.

Step 6: Fuzzy decision matrix is made using the judgmental values from project decision-makers for each decision alternative based on each criterion as shown in Table 5.13.

Step 7: Compute normalized fuzzy decision matrix.

A normalized fuzzy decision matrix is made by dividing each fuzzy evaluation matrix with the maximum of each criterion lower value using the following equation.

$$r_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \; and \; c_j^* = {}^{max}{}_j(c_{ij}) \; (benefit\ criteria)$$

Here all criteria are considered beneficial because the maximum value for all is desired. An excerpt of the normalized fuzzy decision matrix for **ShareCompany BIQH** is shown in Table 5.14.

Step 8: Compute weighted normalized fuzzy decision matrix.

The weighted normalized fuzzy decision matrix is made by multiplying fuzzy criteria weights with the normalized fuzzy decision matrix as shown in Table 5.15. The weighted normalized fuzzy decision matrix will be used for determining the positive and negative ideal solutions for each criterion (Step 9). Fuzzy Positive Ideal Solution (FPIS) is denoted by A^* and Fuzzy Negative Ideal Solution (FNIS) is denoted by A^-.

Step 10: Distance from each alternative to the FPIS (A^*) and to the FNIS (A^-) is output in Table 5.16.

$$d(x, y) = \sqrt{\frac{1}{3}[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]}$$

For example, according to the case study, weighted normalized fuzzy decision value for Ethereum (case study 1) is (0.053, 0.072, 0.090) and FPIS (A*) is (0.053, 0.072, 0.090). Based on the equation, distance from Ethereum to the FPIS (A^*) for criteria 1 is calculated as follows:

SQRT ((1/3) *(((0.053-0.053)^2) + ((0.072- 0.072)^2) + ((0.090- 0.090) ^{2}))) = 0

Table 5.13 Excerpt of Fuzzy decision matrix for ShareCompany BIQH

Weights	0.059	0.072	0.090	0.059	0.072	0.090	0.059	0.072	0.090	0.059	0.072	0.090	0.059	0.072	0.090
	C1			C2			C3			C4			C5		
A1- Ethereum	9.000	10.000	10.000	9.000	10.000	10.000	9.000	10.000	10.000	9.000	10.000	10.000	9.000	10.000	10.000
A2- R3 Corda	9.000	10.000	10.000	9.000	10.000	10.000	9.000	10.000	10.000	9.000	10.000	10.000	9.000	10.000	10.000
A3- JPMorgan Quorum	9.000	10.000	10.000	9.000	10.000	10.000	9.000	10.000	10.000	9.000	10.000	10.000	9.000	10.000	10.000
A4- Hyperledger Fabric	9.000	10.000	10.000	9.000	10.000	10.000	9.000	10.000	10.000	9.000	10.000	10.000	9.000	10.000	10.000

Table 5.14 Excerpt of normalized fuzzy decision matrix for ShareCompany BIQH

Weights	0.059	0.072	0.090	0.059	0.072	0.090	0.059	0.072	0.090	0.059	0.072	0.090	0.059	0.072	0.090
	C1			C2			C3			C4			C5		
A1- Ethereum	0.900	1.000	1.000	0.900	1.000	1.000	0.900	1.000	1.000	0.900	1.000	1.000	0.900	1.000	1.000
A2- R3 Corda	0.900	1.000	1.000	0.900	1.000	1.000	0.900	1.000	1.000	0.900	1.000	1.000	0.900	1.000	1.000
A3- JPMorgan Quorum	0.900	1.000	1.000	0.900	1.000	1.000	0.900	1.000	1.000	0.900	1.000	1.000	0.900	1.000	1.000
A4- Hyperledger Fabric	0.900	1.000	1.000	0.900	1.000	1.000	0.900	1.000	1.000	0.900	1.000	1.000	0.900	1.000	1.000

Table 5.15 Excerpt of Weighted Normalized fuzzy decision matrix, FPIS and FNIS values for ShareCompany BIQH

Weights	0.059	0.072	0.090	0.059	0.072	0.090	0.059	0.072	0.090	0.059	0.072	0.090	0.059	0.072	0.090
		C1			C2			C3			C4			C5	
A1- Ethereum	0.053	0.072	0.090	0.053	0.072	0.090	0.053	0.072	0.090	0.053	0.072	0.090	0.053	0.072	0.090
A2- R3 Corda	0.053	0.072	0.090	0.053	0.072	0.090	0.053	0.072	0.090	0.053	0.072	0.090	0.053	0.072	0.090
A3- JPMorgan Quorum	0.053	0.072	0.090	0.053	0.072	0.090	0.053	0.072	0.090	0.053	0.072	0.090	0.053	0.072	0.090
A4- Hyperledger Fabric	0.053	0.072	0.090	0.053	0.072	0.090	0.053	0.072	0.090	0.053	0.072	0.090	0.053	0.072	0.090
A*	**0.053**	**0.072**	**0.090**	**0.053**	**0.072**	**0.090**	**0.053**	**0.072**	**0.090**	**0.053**	**0.072**	**0.090**	**0.053**	**0.072**	**0.090**
A-	**0.053**	**0.072**	**0.090**	**0.053**	**0.072**	**0.090**	**0.053**	**0.072**	**0.090**	**0.053**	**0.072**	**0.090**	**0.053**	**0.072**	**0.090**

Table 5.16 Excerpt of distance from FNIS and distance from FNIS for ShareCompany BIQH

	Distance from FPIS														
A1- Ethereum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.019
A2- R3 Corda	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.000	0.019	0.000	0.000
A3- JPMorgan Quorum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.008	0.000
A4- Hyperledger Fabric	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000
	Distance from FNIS														
A1- Ethereum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.000	0.019	0.000	0.000
A2- R3 Corda	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.019
A3- JPMorgan Quorum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.000	0.000	0.005	0.019
A4- Hyperledger Fabric	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.000	0.019	0.005	0.019

Step 11: Compute the closeness coefficient CCi for each alternative

To calculate the closeness coefficient CC_i for each alternative, D_i^* and D_i^- needs to be calculated. CC_i is computed by dividing D_i^- with the summation of D_i^* and D_i^-. Values for D_i^* and D_i^- is calculated by adding distances from each alternative to the FPIS and FNIS respectively for all criteria. Results are shown in Table 5.17 to Table 5.19.

Table 5.17 D_i^* and D_i^- values for ShareCompany BIQH

d_i^*	d_i^-
0.069	0.110
0.088	0.085
0.091	0.092
0.042	0.143

Table 5.18 D_i^* and D_i^- values for DUO

d_i^*	d_i^-
0.060	0.239
0.137	0.163
0.159	0.141
0.117	0.177
0.159	0.132
0.216	0.076
0.194	0.092

Table 5.19 D_i^* and D_i^- values for Veris Foundation

d_i^*	d_i^-
0.018	0.057
0.037	0.038
0.043	0.032
0.025	0.050
0.057	0.018

Step 12: Rank the alternatives

The ranked list of alternatives with the highest value is ranked as one and the alternative with the lowest value is ranked as last was generated for each case study. The final ranked lists for these three case studies are shown in Table 5.20 to Table 5.22.

Final stage: Select the most appropriate blockchain platform

According to Table 5.20 to Table 5.22, Hyperledger Fabric is the blockchain platform that scores the highest value and can be selected as the most appropriate platform for Case Study 1 (ShareCompany BIQH). On the other hand, Ethereum is recommended as the most appropriate blockchain platform for Case Study 2 (DUO) and Case Study 3 (Veris Foundation).

Table 5.20 CC_i values for each alternative and Ranking (ShareCompany BIQH)

	CC_i	Rank
A1- Ethereum	0.615	2
A2- R3 Corda	0.491	4
A3- JPMorgan Quorum	0.504	3
A4- Hyperledger Fabric	0.774	1

Table 5.21 CC_i values for each alternative and Ranking (DUO)

	CC_i	Rank
A1- Ethereum	0.799	1
A2- Hyperledger Fabric	0.542	3
A3- Hyperledger Sawtooth	0.470	4
A4- NEO	0.601	2
A5- Stellar	0.453	5
A6- Waves Platform	0.260	7
A7- Komodo	0.320	6

Table 5.22 CC_i values for each alternative and Ranking (Veris Foundation)

	CC_i	Rank
A1- Ethereum	0.756	1
A2- Hyperledger Fabric	0.513	3
A3- Hyperledger Sawtooth	0.423	4
A4- NEO	0.667	2
A5- Stellar	0.244	5

5.2.5 Results

Table 5.23 presents a comparison of ranking results obtained from FAT-BPSM with the results obtained from DSS proposed in P16 (Farshidi et al., 2020) for these three case studies.

Table 5.23 Comparison of the case studies results

Case Study	Results from P16	Results from this study
Case Study 1: ShareCompany BIQH	1. Hyperledger 2. JPMorgan Quorum	1. Hyperledger Fabric 2. Ethereum 3. JPMorgan Quorum 4. R3 Corda
Case study 2: DUO	1. Ethereum 2. NEO 3. Hyperledger	1. Ethereum 2. NEO 3. Hyperledger Fabric 4. Hyperledger Sawtooth 5. Stellar 6. Komodo 7. Waves platform
Case study 3: Veris Foundation	1. NEO 2. Ethereum	1. Ethereum 2. NEO 3. Hyperledger Fabric 4. Hyperledger Sawtooth 5. Stellar

As illustrated in Table 5.23, Hyperledger Fabric is ranked as number one for ShareCompany BIQH software development company which means it is the most highly recommended blockchain platform. Further, Ethereum is determined as the most appropriate platform for DUO and Veris Foundation companies which also means this blockchain platform supports all blockchain feature requirements with very important priority and fulfils nearly all the criteria requirements with standard and optional priority.

For Case Study 1 (ShareCompany BIQH), JPMorgan Quorum is ranked as third while in DSS suggested in P16 (Farshidi et al., 2020), it is the second most highly ranked platform. Ethereum and R3 Corda were not shortlisted in the DSS, but the proposed FAT-BPSM considered them as alternative platforms.

Shortlisted alternatives and rankings are nearly the same for both DUO and Veris Foundation companies. For Case Study 2 (DUO), the ranking of the top three platforms (i.e., Ethereum, NEO and Hyperledger) is the same for both studies. In this study, there are three additional platforms shortlisted as alternatives (i.e., Stellar, Komodo and Waves platforms).

For Case Study 3 (Veris Foundation), the results of number one and number two are contrariwise (i.e., NEO and Ethereum).

Another important observation is that the mapping information in the DSS knowledge base is not always correct for some features, or the features may be added recently to the platforms but were not updated in the DSS knowledge base. This also affects the results of shortlisted alternatives in these three case studies.

5.2.6 Discussion

This section discusses the results presented in the previous section. All steps of the proposed selection method were accordingly taken for solving the blockchain platform selection problem in this case study. The ranked list of alternatives has fulfilled all the objectives, features and quality attribute criteria defined for these software companies.

The results presented in Section 5.2.5 confirm that the proposed Fuzzy AHP-TOPSIS selection method provides a more accurate ranked list of blockchain platforms compared to DSS to help software-producing organizations in their initial decisions for blockchain platform selection. In other words, the proposed selection method recommended nearly the same blockchain platforms as suggested by DSS. Additionally, the proposed FAT-BPSM evaluates blockchain platforms based on a more comprehensive set of criteria consisting of features and quality attributes as compared to DSS. In the case studies, three group divisions using the Numerical Assignment Technique are used to prioritize requirements which ease the prioritization task as compared to MoSCoW method, since the "won't have" group is often ignored by decision-makers or may have the same priority as "Does not matter" with the possibility of consideration in the future.

Several studies have attempted MCDM techniques for blockchain platform selection models. However, the usage of integrated MCDM techniques in the context of selecting a blockchain platform is rare. The selection of the best blockchain platform involves complex decision variables. Since a single method is not sufficient to identify the best fitting blockchain platform, there exists a need to apply the integrated approach to solve this problem. Moreover, the updated and validated version of the mapping information is useful and valuable in finding a more proper list of feasible blockchain alternatives.

Based on the analyzed results, it is proved that the Fuzzy AHP-TOPSIS Blockchain Platform Selection Method is accurate in selecting the most appropriate platform based on requirements in a real industrial context. The proposed selection method provides a systematic approach to support the decision-making process by considering a larger set of criteria and precise mathematical calculations.

5.3 Evaluation of the identified selection criteria and alternative blockchain platforms

5.3.1 Data Collection

A survey was conducted to get the opinions of blockchain practitioners on the suitability of the features and quality attributes identified as selection criteria for the evaluation and selection of Blockchain platforms. In addition, 30 blockchain platforms that are more commonly used in the existing studies were shortlisted as potential alternatives that can be used in the comparison and selection of Blockchain platforms for different application domains (see Section 2.6.2). The opinions from practitioners have also been collected on the suggested application domains that they think are more fitted for the listed blockchain platforms. The application domains included in the questionnaire are Financial applications, Integrity verification, Governance, IoT, Healthcare Management, Privacy and security, Business and Industrial applications, Education and Data management. These domains were identified from the existing studies as the main application domains for blockchain applications.

An online questionnaire was designed using Google Forms to collect data for this survey. The importance of evaluation criteria was measured using a 5-point importance Likert-type scale, ranging from "Very Important" to "Not Important". The questionnaire was distributed electronically via social media groups such as LinkedIn, Twitter, WhatsApp, University email and emails to students, IT professionals, or those who were directly or indirectly involved in IT or technology projects. A total of 28 responses were received. Out of the 28 respondents, only 12 respondents are blockchain practitioners that had experience using blockchain platforms in their projects. Hence, this survey only includes the data collected from these 12 respondents for analysis. Appendix A presents the questionnaire used in this evaluation.

5.3.2 Results

The results collected from the survey were analyzed and presented in Tables 5.24 to Table 5.25. As shown in Table 5.24 and Table 5.25, each Likert-type scale is given a score, i.e., Very important score= 5, Important score=4, Moderately Important score=3, Slightly Important score=2 and Not important score=1. The average score on the importance of all features and quality attributes was calculated by dividing the total score by the number of total responses.

Table 5.24 Data analysis on the importance of features as selection criteria

Feature	Number of Participants per Likert scale					Total responses	Total	Average
	Very Important (Score=5)	*Important (Score=4)*	*Moderately Important (Score=3)*	*Slightly Important (Score=2)*	*Not Important (Score=1)*			
Consensus Mechanisms	8	3	1	0	0	12	55	4.583
Network types	6	3	1	1	1	12	48	4.000
Cryptocontract	4	5	3	0	0	12	49	4.083
Blockchain tokens	6	4	1	0	1	12	50	4.167
Privacy feature	8	3	1	0	0	12	55	4.583

Table 5.24, continued

Feature	Number of Participants per Likert scale					Total responses	Total	Average
	Very Important (Score=5)	*Important (Score=4)*	*Moderately Important (Score=3)*	*Slightly Important (Score=2)*	*Not Important (Score=1)*			
Scalability feature	8	2	1	1	0	12	53	4.417
Programming language	4	3	3	2	0	12	45	3.750
Privacy/Anonymity feature	6	4	2	0	0	12	52	4.333
Interoperability feature	4	3	4	1	0	12	46	3.833
Resilience feature	2	4	4	1	0	11	40	3.636
Structure	4	2	5	1	0	12	45	3.750
Data Model	7	0	4	1	0	12	49	4.083

As presented in Table 5.24, all features obtained an average score greater than 3.6, therefore it shows that all the identified features are considered as suitable selection criteria in the comparison and selection of blockchain platforms. Privacy feature and Consensus Mechanisms obtained the highest average score (4.583); hence they are the most significant selection features according to feedback from blockchain practitioners. On the other hand, resilience obtained the lowest average score but still fall between moderately important and important, which is still suitable to be included as one of the selection criteria.

Based on Table 5.25, all quality attribute criteria obtained an average score greater than 3.8, falling between important and moderately important. As a result, these identified criteria can be considered as suitable selection criteria in the evaluation and selection of blockchain platforms. Security and performance efficiency obtained the highest average score (4.5); hence they are the most significant quality attributes based on the opinions of blockchain practitioners. Although the supplier criterion obtained the lowest average score (3.818), the value is more than 3 which indicate that it can be considered as a suitable selection criterion.

Table 5.25 Data analysis on the importance of quality attribute criteria as selection criteria

Quality Attribute / Non-functional Criterion	Number of Participants per Likert scale					Total responses	Total scores	Average
	Very Important (Score=5)	*Important (Score=4)*	*Moderately Important (Score=3)*	*Slightly Important (Score=2)*	*Not Important (Score=1)*			
Functional suitability	7	3	2	0	0	12	53	4.417
Performance efficiency	6	6	0	0	0	12	54	4.500
Compatibility	4	5	3	0	0	12	49	4.083
Usability	8	2	1	1	0	12	53	4.417
Reliability	6	3	3	0	0	12	51	4.250
Security	8	2	2	0	0	12	54	4.500
Maintainability	7	2	2	1	0	12	51	4.250
Portability	6	3	1	2	0	12	49	4.083
Product	2	6	4	0	0	12	46	3.833
Supplier	2	6	2	1	0	11	42	3.818
Cost	3	5	4	0	0	12	47	3.917
Size	5	3	2	2	0	12	47	3.917
Privacy	7	5	0	0	0	12	55	4.583

Table 2.6 shows the analysis of the suitability of the blockchain platforms for different application domains. Only 8 respondents replied to this part of the questionnaire. As we can see from the analysis, all the platforms are suitable to be used in at least three application domains. Ethereum, BigChainDB and Litecoin are three blockchain platforms that can be used in all the listed application domains. Besides, Hyperledger (Fabric), Bitcoin and Ripple are the blockchain platforms that are also considered as suitable blockchain platforms in most of the listed application domains.

Table 5.26 Number of responses on the suitability of the blockchain platforms for each application domain

Blockchain Platform	Financial applications	Integrity verification	Governance	IoT	Healthcare Management	Privacy and security	Business and Industrial	Education	Data	Miscellaneous
Ethereum	6	4	3	3	1	2	3	2	1	1
R3 Corda	4	1	1	1	0	1	0	0	0	1
JPMorgan Quorum	3	2	1	2	1	0	0	0	0	0
Hyperledger platforms	2	5	6	3	3	4	2	0	1	0
Hyperledger (Fabric)	2	5	5	2	3	2	2	0	1	0
Hyperledger (Sawtooth)	1	4	1	1	4	1	0	0	0	0
BigChainDB	2	2	2	2	2	2	2	2	1	1
MultiChain	2	2	3	1	1	0	1	1	1	0
HydraChain	1	2	3	1	1	1	1	1	0	0
Chain	1	4	1	0	1	0	1	1	0	0
Stratis (Azure Baas)	3	1	1	1	1	2	2	0	0	0
NEO	2	1	2	1	0	2	2	1	1	0
Cardano	0	1	0	1	0	0	3	0	1	0
Stellar	3	0	1	1	0	1	2	2	1	0
Ripple	5	2	1	4	2	0	0	0	1	0
Bitshares	3	2	1	0	0	2	1	0	0	0
QTUM	2	1	1	1	0	0	4	0	0	0
IOTA	2	2	3	3	1	0	1	0	0	0
Lisk	1	0	1	0	0	0	2	0	0	0
Waves Platform	0	2	1	2	0	1	3	0	0	0
Komodo	0	1	1	1	1	2	2	0	0	0
Bitcoin	4	3	0	1	1	1	2	1	1	1
Zcash	4	1	0	1	2	2	0	0	0	0
Litecoin	2	4	0	4	1	2	2	2	1	1
Dash	3	1	1	1	0	1	2	1	0	0
Peercoin	0	2	1	1	0	2	1	1	0	0
Monero	2	2	1	2	1	3	1	0	0	0
Tendermint	3	1	2	0	0	2	1	0	0	0
Eris	1	2	2	1	0	2	2	0	0	0
EOS	1	1	2 2 0	1	3	0		0	0	

5.3.3 Discussion

The results of this survey prove that all selection criteria and alternative blockchain platforms identified from the existing studies are suitable for the comparison and selection of blockchain platforms. As a result, this study has collected information for each platform based on this set of selection criteria to develop a mapping that can be used as a knowledge base to support the decision-making process. The number of selection criteria and alternative blockchain platforms were shortlisted again later to exclude the criteria and platforms that have limited or no information, which is hard to build a complete knowledge base. The final lists of selection criteria and alternative blockchain platforms included in this study are presented in Section 4.2.1.

Among the selection criteria, privacy features, consensus mechanisms, security and performance efficiency are significant criteria that can have more impact in comparison to the other criteria when selecting a blockchain platform. Although resilience features and suppliers are also suitable criteria, they uphold lesser importance in comparison to other evaluation criteria based on the survey results.

Based on the results obtained for the alternative blockchain platforms, Ethereum, BigChainDB and Litecoin, Hyperledger (Fabric), Bitcoin and Ripple are popular blockchain platforms that are suitable to be used in many application domains. Among all the domains, Finance, Integrity verification, Governance, and IoT are identified as common domains that can adopt blockchain platforms in their applications.

5.4 Applicability of the Fuzzy AHP-TOPSIS Blockchain Platform Selection Method (FAT-BPSM)

In this evaluation, the applicability check method proposed by Rosemann and Vessey (2008) is adapted to evaluate the applicability of FAT-BPSM.

5.4.1 Data collection and analysis

The seven steps of the applicability check method were adopted for data collection and analysis of this evaluation. Each step is elaborated in the following subsections.

Step 1: Planning the applicability check

"Effective planning is the key to conducting a successful applicability check" (Rosemann & Vessey, 2008). The objective of the applicability check is to apply FAT-BPSM for the comparison and selection of the most appropriate blockchain platform based on the project requirements given by the blockchain experts.

The criteria for selecting blockchain experts for this evaluation are as follows:

1. Have in-depth knowledge about blockchain technology and decision-making processes
2. Have sufficient experience in using different blockchain platforms in their projects
3. Actively involved in research related to blockchain
4. Have published several research articles (i.e., conference and journal papers) related to blockchain

In an attempt to check the applicability of the proposed selection method in a real-world project context, two blockchain experts that have fulfilled all the criteria are invited to participate in this evaluation. These two blockchain experts are working as senior research scientists at a science and research organization in Australia. Each expert has selected a project in the organization to apply FAT-BPSM to choose the most appropriate blockchain platform based on the project requirements.

Step 2: Selecting the person to conduct the check

My research supervisor was selected as the moderator to conduct the applicability check. She was selected because she has in-depth knowledge of the research, proper social skills, and the ability to listen and ask proper follow-up questions. In addition, she ensured not to bias the responses of the participants.

Step 3: Ensuring that participants are familiar with the research object under examination

An online session was arranged through the Webex communication portal to get the two blockchain experts to familiarize themselves with the proposed method, FAT-BPSM. During the session, the research objectives were clearly defined, and the application of the proposed method was explained in detail with the help of case studies. After the session, participants in the check are provided with materials i.e., presentation slides which included an introduction of the research, research objective, an overview of the proposed method and an explanation of the steps applying FAT-BPSM in the comparison and selection of blockchain platforms. This ensures that prior to the applicability check, both experts have sufficient information about the research object to effectively participate in the evaluation.

Step 4: Designing the materials for conducting the check

It is clear that designing and preparing the materials for the applicability check also 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" (see Appendix B) was designed using Google Forms to collect project requirements. In the questionnaire, each participant was required to give project information, select, and prioritize the blockchain feature requirements according to the Numerical Assignment Technique. The "Very Important (critical)" features were used to shortlist the alternatives blockchain platforms for each project.

The "Alternatives Rating Questionnaire" (see Appendix C) 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 quality attributes.

On the other hand, the "Post-evaluation Questionnaire" (see Appendix D) was designed to collect feedback from participants to evaluate the applicability of the proposed selection method and suggestions for the improvement of the proposed selection method.

All the necessary information the participants needed to know when selecting and prioritizing their project requirements were given in the questionnaire (i.e., description of selection criteria, description of alternatives blockchain platforms and mapping information of quality information for each alternative platform). Hence it will not cause any confusion or error during the application of the proposed FAT-BPSM in the selection of blockchain platform for each project.

Step 5: Establishing an appropriate environment for conducting the check

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. A Google Meet invitation was sent to both participants for this evaluation discussion session.

Step 6: Conducting the check

The experts were provided with the "Project Requirement Gathering Questionnaire" (Appendix B) to prioritize their project requirements based on the Numerical Assignment Technique. After the filled forms are fetched back, another questionnaire, "Alternatives Rating Questionnaire" (Appendix C) had sent to them to rate the possible alternatives for each of the quality attributes by referring to the mapping information (knowledge base) for quality attributes. To rate the features criteria, the feature criterion was rated "very good" if the feature is supported by the platform and the feature criterion was rated "very poor" if the platform does not support the feature.

When the experts submit their rating forms, the selection stage was conducted based on the steps proposed in FAT-BPSM. In the final stage, a ranked list of alternative blockchain platforms was recommended by FAT-BPSM for each project. In the evaluation discussion session, the results of the blockchain selection were presented to the experts. During the discussion session, each expert gave comments about the results and provided feedback on the applicability and improvement of the proposed method.

Step 7: Analyzing the data

After the discussion session, the "Post-evaluation Questionnaire" (Appendix D) 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.

5.4.2 Results

The blockchain experts used two projects in their organization to evaluate the applicability of the FAT-BPSM. 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.

Based on the "Very Important (critical)" features collected from project requirements, three alternative platforms were shortlisted for comparison. The first expert prioritized 54 criteria (i.e., 10 very important features, 39 very important quality attributes, 5 rather important features) to compare and evaluate the three alternatives for the HA project. On the other hand, 87 criteria (i.e., 6 very important features, 4 very important quality attributes, 18 rather important features, 25 rather important quality attributes, 22 optional features and 12 optional quality attributes) were prioritized by the second expert for the MCE project. 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 5.27 and Table 5.28. As shown in the results, Hyperledger Fabric was recommended as the most appropriate blockchain platform for the HA project while Stratis Azure Baas was ranked number one for the MCE project.

Table 5.27 Hydrogen Accreditation (HA)

	CC_i	Rank
A1- Ethereum	0.300	2
A2- JPMorgan Quorum	0.298	3
A3- Hyperledger Fabric	0.822	1

Table 5.28 Measured Circular Economy (MCE)

	CC_i	Rank
A1- Ethereum	0.475	2
A2- Stratis Azure Baas	0.748	1
A3- Stellar	0.420	3

The complete calculations for the HA project can be accessed via this link:

https://docs.google.com/spreadsheets/d/1uxyN4PQxPuM6DWrhvWeP2067CJ2qFIBO/edit?usp=sharing&ouid=103637803201737016932&rtpof=true&sd=true

The complete calculations for the MCE project can be accessed via this link:

https://docs.google.com/spreadsheets/d/1HnfsyY2ng0qPGATwMtlm3QpkPU-8I06B/edit?usp=sharing&ouid=103637803201737016932&rtpof=true&sd=true

Based on the results presented, both experts evaluated the applicability of the proposed FAT-BPSM by giving feedback through the online discussion session and the ratings on the applicability of FAT-BPSM based on the evaluation criteria in "Post-evaluation Questionnaire" (see Table 5.29). Both experts showed strong agreement with the applicability aspects of FAT-BPSM to support the decision-makers in selecting the most appropriate blockchain platform based on the requirements.

Table 5.29 Ratings given by experts on the applicability of FAT-BPSM

Applicability Criteria	Expert 1	Expert 2
1. In the FAT-BPSM, from 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 is 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. Instead of 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. 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. It is hard for them to decide on the criteria. For non-technical decision-makers, characteristics of the business scenarios rather than the technical criteria can be included as selection criteria. Furthermore, the method can be improved by carrying out some trade-off analysis between quality attributes for better judgment on the alternative ratings.

5.4.3 Discussion

The analysis of the evaluation results 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 improvements suggested by both experts are valuable and will be considered for future work of 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 that FAT-BPSM can generate an accurate ranked list of alternatives according to the project requirements.

On the other hand, for the MCE project, this 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.

5.5 Summary

This chapter explains the evaluations conducted to evaluate the accuracy and applicability of the proposed selection method for choosing the most appropriate blockchain platform, and the suitability of the selection criteria in the comparison and selection of blockchain platforms. The first evaluation was conducted using three case studies and the results benchmarked against the results previous study (P16) has proved the accuracy of FAT-BPSM to generate the ranked list of alternative blockchain platforms. In the second evaluation, the suitability of applying the selection criteria and shortlisted alternative blockchain platforms in the comparison and selection of blockchain platforms were examined using a survey. The results show that all the criteria and blockchain platforms identified from existing studies are suitable to be used for the selection of blockchain platforms. In the last evaluation, the results applicability check by two blockchain experts demonstrates that the proposed method, FAT-BPSM is applicable to select the most appropriate blockchain platform based on project requirements in real-world projects.

CHAPTER 6: CONCLUSION

In this research, firstly, a meticulous literature review was conducted to identify important criteria for the comparison and evaluation of blockchains. Further, 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. Existing studies which have applied an integrated approach in different application domains other than blockchain platform selection shows that the integrated approach is a promising technique to overcome the problem of decision-making by cooperating the weaknesses of one method with the strengths of another method. For this reason, a new selection method based on an integration of three MCDM methods - Fuzzy AHP-TOPSIS is proposed by considering both types of criteria (features and quality attributes) to solve the blockchain platform selection problem. The Fuzzy AHP-TOPSIS Blockchain Platform Selection Method (FAT-BPSM) consists of three main stages which are: (1) Pre-selection; (2) Selection stage; and (3) Final Stage: Select the most appropriate blockchain platform.

To evaluate the proposed selection method, case studies, a survey and applicability check by blockchain experts were conducted to demonstrate the accuracy and applicability of FAT-BPSM for the comparison and blockchain platform selection problem. The evaluation also shows that the FAT-BPSM can act as a practical and systematic method for supporting the adoption of blockchain technology in a blockchain-based application. Decision-makers of an organization can select the most appropriate blockchain platform given the project requirement using a set of suitable selection criteria.

6.1 Research Contribution

It is believed that 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 appliable, to select the most appropriate blockchain 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 listed as:

- Carrying out an analysis of existing decision models.
- Identification of important criteria for comparison and selection of blockchain platforms.
- Development of a knowledge base (mapping information) that can be used as a reference for rating the possible blockchain alternatives.
- 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. This combination has not yet been applied in the blockchain application domain.
- The proposed method addresses the limitations identified in the related studies.
- The proposed systematic selection process improves the efficiency of the decision-making process and accuracy in selecting the most appropriate blockchain platform.

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. It is important to mention that the integration of Fuzzy AHP and TOPSIS has not yet been explored in the blockchain application domain. Given the extensive considerations and financial investment on the blockchain platforms, the proposed selection method can be used to ensure the selection of the right platform for blockchain initiatives.

6.2 Fulfilment of Research Objectives

This study discussed four (4) research objectives in chapter one. Throughout this research, each research objective was achieved successfully.

Objective 1: To investigate existing blockchain platforms' features and quality attributes

This study conducted a literature review to identify a list of blockchain platforms' features and quality attributes. The existing features and quality attributes are presented in Section 2.6.

Objective 2: To identify selection criteria (features and quality attributes) that impacts the comparison and selection of all types of blockchain platforms.

From the identified features and quality attributes, those criteria which are suitable and have more impact on the comparison and selection of all types of blockchain platforms are shortlisted by analyzing existing studies (reported in Section 2.6). Besides, a survey was conducted to evaluate the suitability of the identified selection criteria in blockchain platform selection (reported in Section 5.3). This research covers both types of criteria - feature and quality attributes for comparison of all types of blockchain platforms (i.e., permissionless, permission, and private).

Objective 3: To develop a method based on an integrated MCDM technique, Fuzzy AHP-TOPSIS to overcome the limitations of one MCDM technique with another and meet specific project needs.

A new selection method based on an integration of three MCDM techniques - Fuzzy AHP-TOPSIS is proposed in this research which handles one method's imperfection with another. This new selection method, FAT-BPSM can assist decision-makers of an organization to compare platforms based on different features and quality attributes and select the most appropriate platform which meets their prioritized project requirements. The explanation of the steps of the proposed selection method was presented in Chapter 4.

Objective 4: To evaluate the accuracy and applicability of the proposed selection method.

To evaluate the accuracy of the proposed selection method, three case studies were conducted. Each phase and step of the proposed FAT-BPSM is applied to these case studies to select the most appropriate blockchain platform. Moreover, the expert review was used to evaluate the applicability of the proposed method. The evaluation results show that the FAT-BPSM is applicable and accurate for the evaluation and selection of the most appropriate platform based on project requirements. A detailed explanation of the evaluation is presented in Chapter 5.

6.3 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. Another downside regarding our methodology is that all calculations of the formulas are done using excel sheets, hence the data needs to be inserted manually for some tables which increases the chances of error due to the decimal nature of weights and fuzzy numbers.

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.

Despite the limitations of this method, and consequently the evaluation results in Chapter 5, 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.

6.4 Future work

To the best of our knowledge, no other authors have proposed a platform selection method based on Fuzzy AHP-TOPSIS multi-criteria decision-making techniques in the blockchain domain. Accurate results obtained from case studies show that the methodology works in practical application domains. Future work will concentrate on developing a tool that helps to automate the selection process as suggested by the blockchain experts. Characteristics of the business scenarios can be studied in future research to identify suitable 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 on the blockchain platform quality attributes to provide decision-makers with a more comprehensive reference for alternative rating.

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